Scientific Education

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Invigorating Education**

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academia · chemical education · creativity · global challenges

Introduction

"*The obvious thing that will strike any intelligent American, who has only heard of Plato, and wants to make his acquaintance through Jowett's noble translation, is the amount of time these Dialogues waste in arriving at a conclusion. Nay often they represent a very long conversation which comes to no conclusion at all. Yet that feature is essential to all higher training of human mind. You may appear to the vulgar to be wasting time, and yet it is not wasting time, but doing the best you can for a great object. The earth moving in its orbit need not delay its regular course because it revolves upon its axis, and causes its whole surface to enjoy the blessed light of the sun. And the next thing you will find in Plato's Dialogues (the best exponent of higher education I know) is that the objects in view are not those of sense, or of the material needs of life, or of obtaining success in the world. They all, like Saint Paul's reasonings with Felix, have to do with righteousness and temperance, and judgment to come. But even this field, that of ethical inquiry, is not the highest to which Greek education attained. For their early teachers taught them to think about the universe and its constitution, the nature of mind, the nature of matter, and other high questions of abstract metaphysics.*"

J. P. Mahaffy, 1910[1]

The above quote is just as important today as it was a century ago when spoken and written, for the essence of

Figure 1. John Pentland Mahaffy (1839–1919), Anglo-Irish classics scholar, philosopher, and educator.

Figure 2. Plato (c. 429–347 BC), Greek philosopher. A disciple of Socrates and the teacher of Aristotle, founder of the Academy of Athens, 5th century BC. (Photo: Vasiliki Varvaki, Plato—the Philosopher, iStockphoto.com).

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education should be not only assimilation of knowledge but, most critically, acquisition of the power of thought. So in any discussion on education, chemical or not, we should always keep in mind that creative thinking and the study of the fundamentals of nature are the two most important prerequisites to success in science and technology.

Living today in developed countries has enormous advantages, such as plentiful food and energy, miracle drugs to treat diseases, luxury items and entertainment, easy access to worldwide travel, and means of instant communication, to name a few. As we usher in the dawn of the second decade of the 21st century, we marvel and stand in awe of the achievements of science and technology that gave us these goods and promise to deliver more life-changing discoveries and inventions in the future at a breathtaking pace. The foundation of these world-shaping advances in science and technology is education. This Essay reflects the thoughts of the author, and others to be sure, on the current status and future prospects of chemical education and includes recommendations on how to reinvigorate science education, especially in light of the new realities of globalization and challenges facing society and science today.

Despite all of our current advantages, our world is becoming increasingly materialistic and unevenly privileged and educated. Many will agree that, while progress has been made around the globe, there has been an erosion of values and education in many regions of the world, including the US and parts of Europe, at the same time that we are facing threatening problems that only science can solve. Below I will expound upon the state of secondary, undergraduate, graduate, and postdoctoral education, but first it might be instructive to summarize my own journey through these stages of education as they took me from Europe to America and allowed me to see, subsequently, the world as an educator and a scientist.

Personal Education Perspective

Primary and secondary schools played a major role in my education. I watched my three children as they progressed through their primary and secondary education in the United States and had the privilege of giving lectures to high school students in the United States and Singapore. From those experiences, and from what I learned from talking with people in different parts of the world and reading various articles on education, I know, as others do, of the dramatic differences in the opportunities offered or denied to students around the world, and within a given country like the US. In fact, although not fully cognizant of its significance at the time, I was at the center of the disparity in education in my own country. After transferring from the high school of my home town in Cyprus to what was then the best high school of the island at the age of 13, I ended up for the first half of the year at the bottom of my class in math and literature. Needless to say, I was devastated, for I was a good student in previous years and was not accustomed to that predicament. Fortunately, I responded to the higher standards and the better curriculum of the new school, so that by the end of the academic year I received sufficiently higher grades to erase the embarrassment, received praise from my teachers, and gained my confidence back. My new teachers at the Pancyprian Gymnasium in Nicosia (1959–64) were extremely well educated with a minimum of a bachelor degree from good universities in Europe or the US. Some even had higher degrees, like my chemistry teacher (Dr. Telemachos Charalambous; Figure 3), whose training included a Ph.D. from France. He was my role model and inspired me to study chemistry at the young age of 16. I am deeply grateful for the fact that I could attend such a stellar school, like many other students on the island, irrespective of financial status, for the fees were nominal and affordable. The Pancyprian Gymnasium benefited from the British system, whose positive influence on education was paramount during the period that Great Britain ruled the island (1878–1960). In addition to

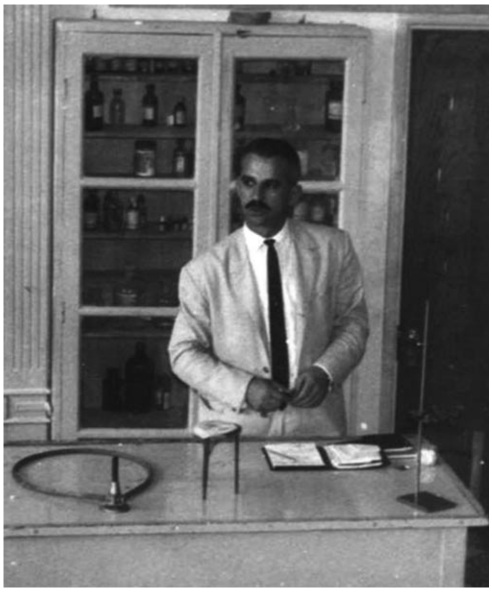

Figure 3. Dr. Telemachos Charalambous, my inspirational chemistry teacher at the Pancyprian Gymnasium, Nicosia, Cyprus (Photo courtesy of Merope Tsimilli-Michael).

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having well trained teachers, this high school offered three tracks for its students in the final three grades. These tracks had tailor-made curricula for students interested and capable in science and math, classical studies (literature, arts, humanities), and finance and business. While students in each track were guided toward a set of related disciplines, they still followed a general education curriculum that allowed for broad education and future flexibility to choose a specific career path, specialized or otherwise.

In attempting to enter a university in the UK, I applied as a chemistry major and so did everyone else in my class. Students entering a university prepared themselves in high school for the subjects they would follow, a practice that still prevails today in the UK and a number of other developed countries. In contrast, the US system allows students to enter colleges and universities with undeclared fields of study, leaving them with flexibility to choose their major subject (usually during the first two years of a normal four-year study for a B.S. or B.A. degree). As good as it sounds, in some cases this flexibility could lead to indecisiveness and procrastination in terms of identifying and focusing on one's strengths and passion for a subject to study in depth. On the other hand, the American system of open enrollment and electives has its advantages in that it allows for a broader education that proves useful for interdisciplinary studies that are becoming increasingly important in solving certain specific or global problems. In my case, it was certainly a blessing that I already had my mind set on a career in chemistry at a very early age. The only decision I had to make at the college level was the branch of chemistry in which to specialize. This decision came to me naturally and gradually as I progressed through my undergraduate, graduate, and postdoctoral studies, narrowing my choice at each stage for further specialization. My first year at Bedford College, University of London (1966–69), included instruction in chemistry, physics, and math; the second year was fortified with more chemistry courses - organic, physical, and inorganic. The third and final year required even more focused courses and laboratories in my field of choice, organic chemistry, including a research project under the supervision of a faculty member. This intense and progressively focused system allowed me to identify the subdiscipline of chemistry that excited me the most and prepared me to make the next decision in my career, namely choosing a school and a mentor for my Ph.D. degree.

In my three-year graduate studies program at University College, University of London (1969–72), I focused entirely on the synthesis and study of theoretically interesting molecules aiming to probe aromaticity. No courses were required or offered on advanced topics, something that, in retrospect, was a deficiency of the system, since it left the students to their own devices to delve more broadly into chemistry and its surrounding disciplines. My rewarding, three-year Ph.D. experience, however, short as it was, positioned me well to make my next move, which brought me to New York City and Columbia University for postdoctoral studies.

The American scene as I first experienced it at Columbia in 1972 was more dynamic and demanding than the British, but I adjusted quickly and benefited enormously from the special ambiance of Columbia's outstanding department of chemistry. Most fortunately and thanks to the support and advice from my mentor, I landed a position at Harvard University a year later for further postdoctoral studies. At Harvard, I had the opportunity to attend advanced graduate and research lectures on the logic of chemical synthesis and to discover my true and final passion, the total synthesis of complex, biologically active, natural and designed molecules. At that time (1973–76), the US was on the move as the undisputed leader in the world not only in chemical higher education and training, but also in science and technology in general, a condition that ensured the country's supremacy as the land of opportunity, economic growth, and prosperity for decades to come. Many students from all over the world interested in science or engineering wanted to come to the US to join the inspired and motivated Americans in their studies and the pursuit of career opportunities that seemed to be attractive and endless.

Both of my postdoctoral experiences in the US were extremely enriching and rewarding in terms of broadening my knowledge and expertise beyond my Ph.D. studies and shaping my future career as I specialized in chemical synthesis. In addition, the opportunity to experience the atmosphere of Columbia and Harvard and encounter some of the major figures in chemistry was invaluable to me. Indeed, these experiences were so decisive and influential that I can say with confidence that without them I could not have risen to the level I enjoy today as a professor and scientist. Like many others, I was a beneficiary of a superb postdoctoral training system and the recipient of a golden opportunity to stay and establish my career in the US as I chased the American dream. It started at the University of Pennsylvania where I joined the faculty in 1976.

In addition to my responsibilities as professor and research investigator at The Scripps Research Institute and the University of California, San Diego, US, I served as an advisor to a number of pharmaceutical and biotechnology companies, as well as A*STAR, Singapore, an experience that gave me the opportunity to observe and learn from yet another educational system. It is from the perspectives gained in these varied institutions that this Essay was written.

Global Problems Facing Society and Science Today

Even with all the advantages of progress and prosperity, the world today faces a number of serious challenges. These include food (quality and productivity), energy (clean, alternative, renewable), raw materials (versatile, renewable, high tech), health care (effectiveness, affordability, accessibility), environment (climate change, responsibility), information technology (spread, security, control), sustainability (population, resources, responsibility), globalization (wealth, immigration, jobs), and war and terrorism (chemical, biological, nuclear, cyber). While science and technology are at the heart of the campaign to solve these problems, it is the will of the people and their governments that will provide the mandate and the fuel for their solutions. And it all begins with education. Just as scientists need to be knowledgeable in the liberal arts and humanities as part of their citizenship in a cultured and civilized society, so does everyone else need to be informed and knowledgeable of the importance and value of science and technology to society. This understanding by the public is necessary in order to facilitate appreciation and appropriation of funds for research and innovation purposes. Strengthening and promoting education and science, therefore, are the most important visionary actions humanity can take in order to ensure the sustainability and prosperity of the planet for generations to come. The aim should be to disseminate scientific information and knowledge to all students, beginning at pre-secondary education, so as to convey to them both the importance of science to society and the excitement it provides as a career. This will ensure a science-conscious and science-literate public that would be favorably disposed to increase and sustain funding for research and provide the foundation for talented students to pursue advanced studies in science and engineering. The favorable consequence of the latter will be a healthy and continuous pipeline of highly trained scientists and engineers for the next generations.

Chemistry is well-positioned to address aspects of almost all of these issues, but first it needs to adjust and redirect some of its efforts toward new frontiers as defined by the challenges of today and tomorrow. I hasten to add, however, that in doing so we must keep in mind the importance of maintaining the fundamentals of our science at the core of our educational system. Defining new directions of research for chemistry will require invigorating chemical education, beginning with identifying the challenges we face, training the teachers of tomorrow, attracting talented students to the molecular sciences, and securing sufficient funds to implement these plans. In defining these visions and making these adjustments, we need to consider the current global realities and the demands of industry.

Demands and Global Realities in the Chemical and Pharmaceutical Industries

The advent of organic synthesis, together with the emergence of the concept of the molecule[2,3] in the nineteenth century, proved to be one of the most influential discoveries of all time. It led to a revolution in the molecular sciences and a major industrial surge that saw the birth of the chemical and pharmaceutical industries, first in Europe and then the US. These industries shaped the world as we know it today as myriad new products such as dyes, fuels, polymers and plastics, agrochemicals, vitamins, cosmetics, pharmaceuticals, diagnostics, and high tech materials were discovered and developed, flooding the market and increasingly penetrating societies in all continents. The pharmaceutical industry, in particular, now includes, in addition to small molecule drugs, proteinoic drugs. These proteinoic drugs, also known as biologics (including drugs, vaccines, and diagnostics), arose from the advent of biotechnology. Just like the others, this industry has recently undergone major changes along trends which continue to shape its future, including competition from generics, acquisitions and mergers, outsourcing active ingredients and research, including medicinal and process chemistry. The major pharmaceutical companies (so-called big pharma) are performing less internal research and are transitioning into primarily development and marketing companies. It is also interesting to note that these changes occurred coincidentally with the passage of the management of the pharmacetical companies from scientists to business leaders.

Global changes over the last century resulted in major international shifts in the chemical and pharmaceutical industries with the outsourcing of jobs from developed to developing countries as the latter ascended in terms of education, training, and industrial capacity. In more recent times, the world has seen unprecedented industrial and economic shifts that affected not only these major sectors, but also start-up biotech, information technology, and other venture companies (the bridge between academic and industrial research), as well as academic research and the funding entities that support them. In general, venture capital that traditionally fueled entrepreneurship and start-up companies in the US and parts of Europe has become, with some exceptions, more conservative and scarce. Noteworthy is the emergence and success of this sector in Israel, Denmark, and Singapore, three relatively small countries with impressive educational systems, discipline, and visionary leadership. Academic institutions are moving toward more applied or mission-oriented research as opposed to fundamental and basic research, with emphasis on translating basic and applied knowledge into products through innovation. And as funding of academic research in some countries, like the US and UK, has been curtailed, trends toward more industrial-academic collaborations have emerged. The latter phenomenon may become the norm, irrespective of funding from government agencies and philanthropic foundations, as a means to achieve innovation through translation of discoveries to high-value-added products and inventions at a faster pace.

For better or worse, the fate of societies depends largely on financial, corporate, and government institutions that set in motion trends and regulations affecting and shaping some of the most important aspects of our lives. Apparently under inadequate regulations, some of these institutions failed to provide appropriate guidelines and leadership, precipitating unemployment and financial distress to families and corporations alike, not to mention educational and research institutions that also felt the jitters of the recent upheaval. Coincidental to the build up of the current financial crisis was the trend to outsource many of the jobs in the developed to the developing countries, primarily China and India (and the rest of the BRICs = Brazil, Russia, India, China), the awaking giant nations that have the manpower and capacity to absorb the outsourced jobs, mainly manufacturing and servicing. Most significantly, however, the outsourcing movement included high end jobs from the information technology, pharmaceutical, and chemical sectors. The latter, coupled with the merger and acquisition trends within the corporate world, created a crisis of its own for skilled chemists and other scientists and engineers, including B.S., M.S., and Ph.D. level research chemists. The reasons for these massive outsourcings are mainly economic, and were greatly facilitated by development of rapid transportation, the internet, and the revolution in communications. As a result of these recent phenomena, the academic community found itself facing the challenge of making students in developed countries more competitive in the global economy under the present conditions, which favor their counterparts in developing countries where salaries are lower and productivity and skills are on the rise. As unfair as this may seem, the realities of the free market dictate action in academia that if properly planned and implemented may prove beneficial to the entire world in the long run. This response should include not only improvements in education and training to fit the demands of the industry today, but, more importantly, a longer vision toward upgrading education in general and improving appreciation of the importance of science among the public.

This leads to the question of what are the industry's demands and expectations in the current financial and highly competitive global environment. The main reason cited for the outsourcing of high level chemistry jobs (e.g. medicinal and process chemistry) is the perceived favorable ratio of cost vs. productivity. While the effectiveness of this practice may change in the future, as the outsourcing costs increase and its output becomes apparent, we in academia should take advantage of the challenge to educate and train our students to become more competitive and capable of defining and solving problems more economically and faster than ever. The pharmaceutical and biotechnology sectors in particular are facing major challenges as health care becomes increasingly more sophisticated and expensive. They are in constant search of ways to stay competitive and reinvigorate themselves as they move forward to discover, acquire, and develop new drugs for unmet needs. In order to sustain their vitality and vigor they will need to rely heavily on innovation and scientists to achieve it. Industry demands and expects recruits at the Ph.D. level to demonstrate creativity, inventiveness, team-building, good judgment, and above all, problem-solving abilities. And while chemical and pharmaceutical industries welcome scientists with interdisciplinary knowledge and expertise, whose value is undeniable, they uniformly stress the importance of having specialists on board, as they recognize that these are the most likely to succeed in solving their specific problems. The situation facing chemists today, especially in developed countries, should serve as a call to arms for adjustments and improvements in chemical education in order to improve the competitiveness of our students in the global economy. More importantly, we have an opportunity to upgrade and improve chemical education in particular, and science education in general, with the long term vision of understanding nature and translating the gained knowledge into innovations, thereby promoting prosperity and sustainability. The following discussion includes ideas to this end, which are neither exclusively mine, nor necessarily the only ones worth exploring. In addition to invigorating education, however, we must have the courage to point out that excessive and sudden outsourcing from traditionally industrialized to emerging economies is damaging and must be restrained if we are to succeed in reaching the harmony we seek.

Invigorating Education

Science and technology served society generously over the last two centuries. By probing nature and its laws through observation, experimentation, and theory, scientists made astounding discoveries and stockpiled knowledge that enabled inventions prolonging life expectancy, improving transportation and communication, and providing comfort and entertainment to millions of people around the globe.

As we move forward our reliance on science and technology will become more acute. Science education is perhaps the single most important and visionary priority we can set for ourselves in order to attain and sustain a healthy state of our planet and all its inhabitants. Therefore, beginning from the secondary level, students should be seriously exposed to science and made to sense its excitement and the rewards it provides as a career. Regrettably, this is not universally or even satisfactorily happening in many schools around the world today.

Surprisingly, some of these under-achieving schools are found in unlikely places. A recent survey[4] of 400000 students from 57 countries/economies by the Organization of Economic Co-operation and Development (OECD) as part of their Program for International Student Assessment (PISA) to evaluate and compare the knowledge and critical thinking of 15-year old students revealed interesting results (Table 1).

Table 1: Ranking of countries/economies (top 30) on the science scale of 15-year-old students (OECD PISA 2006).[4]

	Country	Science score
1.	Finland	563
2.	Hong Kong	542
3.	Canada	534
4.	Chinese Taipei	532
5.	Estonia	531
6.	Japan	531
7.	New Zealand	530
8.	Australia	527
9.	Netherlands	525
10.	Liechtenstein	522
11.	Korea	522
12.	Slovenia	519
13.	Germany	516
14.	United Kingdom	515
15.	Czech Republic	513
16.	Switzerland	512
17.	Macao-China	511
18.	Austria	511
19.	Belgium	510
20.	Ireland	508
21.	Hungary	504
22.	Sweden	503
23.	Poland	498
24.	Denmark	496
25.	France	495
26.	Croatia	493
27.	Iceland	491
28.	Latvia	490
29.	United States	489
30.	Slovak Republic	488

Most disturbing for the US was the already well-recognized weakness of its students in this regard. Ranked at 29th place, the US students scored 489 out of 1000, below the global average of 500 and significantly below 1st ranked Finland (563) and other developed countries. Even though the US was not the only unlikely underperformer in this survey, this phenomenon is paradoxical for the leading economy and power in the world, and a country aspiring to be a role model for developing countries. The paradox is even more striking when one considers the results of another survey, one of research universities, that placed the US at the top by far as we shall see later. What can be done about this discrepancy between secondary and higher education? Fortunately, much can be done, given the potential resources of the US and the obvious resourcefulness of its people. Easier said than done, however, reinvigorating education in the US, and other countries where it is badly needed, will take change of attitudes and prioritization of resources. Insightful analysis of the PISA data that includes socio-economic factors, characteristics of schools, parental and state support, among others, should prove useful in achieving equity and upgrading education nationally and internationally. The following discussion pertains primarily to chemical education, but also touches upon aspects of science education as a whole, beginning from secondary education through to postdoctoral training.

Secondary Education

If we are to succeed in achieving higher standards in chemical and general education, we must improve and modernize the entire continuum of secondary-undergraduate-graduate-postdoctoral education, a goal that can only be reached through appropriate funding and continuous self-evaluation by the academy. These upgrades must be aimed at streamlining the system while allowing flexibility for the student to exit at any stage with strong skills and the knowledge to succeed in a specialized or interdisciplinary program or position as desired. High school students should be exposed to at least three years of progressive and high level instruction in science, including chemistry, and mathematics.

During this early stage the students should be made to feel the exhilaration and appeal of science and to understand its potential to support technology and engineering, thereby underscoring its enabling applications and impact. This schooling should allow students to explore their interests and discover their talents as well as choose a possible branch of science or engineering for their university studies. Preferably, therefore, they should be applying to those institutions with a strong inclination, if not a declared subject, of major study. A particularly effective way to facilitate an early focus on an area of study is to establish different tracks for students to follow during their last three years of high school. Thus, according to their strengths and interests, they could choose a path geared toward: a) science and math; b) arts and humanities; c) economics and business; or d) technical trades. Another option is to allow students to pick and choose from offered elective classes during the last few years of high school, although the less structured nature of this alternative, while perfectly well-suited for the well-informed, may not provide guidance to the less privileged students.

The aim of an academic system should be for a uniformly educated and well-trained society to a minimum standard so as to achieve civility and culture and avoid large disparity in socio-economic status that may lead to inequalities and various forms of chaos. Not everybody, of course, can become a scientist, and does not have to be, in order to contribute to society and be a good and content citizen. Thus, after secondary education, a sizeable section of the student population may choose to follow a career in a technical trade, to be a professional mechanic, electrician, chef, farmer, or gardener, for example. These trades ought to be considered as important and respectable, and with proper training can be practiced at a high level of professionalism and prove satisfying and profitable. There is a place for everyone in this world and the world needs everybody to play their role optimally, both in terms of self-satisfaction and efficiency. Such balance in education and training should result in a more harmonious society and address some of the global problems arising from unemployment, immigration, and quality of work in certain sectors which are currently underdeveloped. A serious effort should, therefore, be made to advise students who might be inclined and talented in these areas to follow such training. Technical schools should be strengthened and new ones should be established to accommodate these students. In no way, however, should the freedom of choice be denied to anyone.

Outstanding examples of all types of schools exist in the United States and around the world today and they could serve as models for adoption by schools that do not have such structures. At the heart of these improvements lies the training of teachers so that they are qualified to teach discipline, values, and the appropriate subjects with authority and enthusiasm, which in turn demands higher pay and new funding for the envisioned upgrades in education and facilities, including laboratories and instrumentation. Along with these changes, emphasis should be placed on creative thinking, problem-solving skills, and writing skills, all of which are critical for subsequent educational and professional advancements.

Undergraduate Education

Learned and well prepared from their secondary education, students should arrive at a university with a good idea of their talents and ambitions for their future careers. They should, of course, start with a broad range of courses in their first year in order to set a good foundation for their general education from which to specialize or branch out into interdisciplinary studies. As they proceed to their second and third years, however, and depending on their interests and talents and the advice of their faculty mentors, students should focus on one or two subjects. Some may be able to matriculate with a double major, which may be an advantage in terms of interdisciplinary research or further studies. As early as possible students should identify laboratories for independent research in order to improve their skills beyond the laboratory classes, familiarize themselves with one or more areas of research, and experience the ambiance and realities of graduate school. Such experiences are invaluable to young students, providing them with powerful motivation and preparation for graduate studies. Ideally, undergraduates should know and have realistic expectations by the end of their second year of what they want to do after they complete their undergraduate studies. Some may wish to seek employment in an industrial chemistry or related field right after their bachelor's degree, while some may have the ambition and qualifications to continue their studies at a higher level in a specialized branch of chemistry. Yet another group may decide to follow an interdisciplinary track of further studies, or an entirely new direction in science or engineering for which their chemical education will be an asset or endow them with a special edge. A few daring ones from those majoring in chemistry, may even enter a new domain for themselves such as medicine, finance, law, or entrepreneurship. It should be noted that, at least in the US, organic chemistry classes are populated by large numbers of premedical students.

In addition to strengthening and restructuring their programs, and in order to achieve their mission, undergraduate institutions must enrich their interdisciplinary and elective programs through new courses, and create new tracks for students to follow within disciplinary and interdisciplinary fields. The balance between general education and specialization and increased emphasis on creativity and imagination underscored above for secondary education apply, of course, at the undergraduate level as well. Indeed, these aspects should be intensified and expanded since they become progressively more important and even critical. Outstanding institutions and programs from around the world could serve as models for new universities and colleges, and to those that need improvement, to strive. The tutorial system of the University of Oxford and the University of Cambridge in the UK and the Program of General Education Polices of Harvard University[5] in the US are exemplary in this regard.

Graduate Education

Entering chemistry graduate (doctoral) students should preferably know what track they wish to follow for their Ph.D. studies, whether it is chemical synthesis, chemical biology, physical chemistry, inorganic or organometallic chemistry, polymer science, theoretical chemistry, or a related field offered (or dreamed! such programs could be arranged to fit the interests of the students in some institutions). Faculty should always be on the alert to create new courses and design new tracks in response to new developments in science and technology, the demands of industry, and the global challenges. Today's realities point not only to highly specialized chemists such as those, for example, who know how to synthesize molecules rapidly and efficiently, or those who can perform precise analyses, but also to experts with interdisciplinary knowledge and skills who may be poised to solve different kinds of problems and define new ones. The latter may include synthetic chemists who are knowledgeable or skillful in one or more subdisciplines such as structural biology, bioengineering, microbiology and genetic engineering, molecular and cell biology, neurobiology, physics, materials science, computational chemistry, and computer modeling, among others. However, and most importantly, in addition to these specialized and modern subdisciplines, we must not neglect the fundamentals surrounding them and on to which they stand. For example, in preparing students for the drug discovery and development process that includes medicinal and process chemistry, we must ensure that they receive tuition in the principles not only of mainstream chemical synthesis, but also of biochemistry, heterocyclic chemistry, and physical organic chemistry, fields that are also pivotal and enabling in rationally designing strategies to solve problems in these areas of research.

In addition to diversifying the tracks for students to follow at the graduate level, we should also restructure, modernize and expand graduate courses to include topics such as critical thinking, creativity and imagination, vision and judgment, team-building and leadership, and problem-solving skills, and independence, among others (Table 2). Depending on their inclination, students should also be encouraged to attend selected courses in other disciplines that may widen their horizons and endow them with special knowledge and skills for interdisciplinary research. It should be stressed here again that specialization is highly desirable for some, just as interdisciplinarity is for others. To be sure, both types of scientists have their niche, and they will always be in demand. It is in addition to the specialized tracks that we should seek new ones of interdisciplinary nature, not eliminate one or the other. For example, a synthetic organic chemist versed in X-ray crystallography, computer modeling, and biology may be better equipped to initiate and lead drug discovery programs, while one who also has an entrepreneurial and business background may be successful in starting his/her own biotechnology company. And, a Ph.D. chemist with a genetic engineering background may be in a privileged position to succeed in the important fields of sustainable energy sources and other essential chemicals through discovery programs involving biotransformations, all of which come under the

Table 2: Essentials of good education, training, and values.

Creativity and imagination
Critical thinking
Vision and good judgment
Team-building and leadership
Problem-solving skills
Independence
Communication
Systematic approach
Astuteness and awareness
Continuous learning
Motivation
Discipline and strong work ethic
Integrity
Morality and ethos

umbrella of the emerging discipline of synthetic biology. Such additional experience and skills can be acquired either in graduate school or afterward as part of further postdoctoral studies.

One of the most difficult and, therefore, often neglected subjects in academia is that of how to teach creativity and problem-solving skills. Indeed, such formal courses are rare. They should be more common. Creative thinking and other essentials of good education and training should be an integral part of the entire educational continuum, from kindergarten to postdoctoral training. We must also remember that skills are not sufficient in a civilized society. As parents and teachers we need to instill in our young people from early on the importance of upholding good values such as motivation, discipline, strong work ethic, integrity, and ethos (Table 2). As difficult as teaching creative thinking and problem-solving skills seems to be, it is the most important component of education, and perhaps more crucial now than ever before in the face of automation, information technology, and the internet. At the graduate level, these skills may be best taught with case studies in the classroom and, most importantly, during the research phase of graduate education. Thus, by insisting on truly novel ideas and the pursuit of innovation, mentors can instill in their students the appreciation and practice of creativity and problem-solving skills in their scientific endeavors. Educators should be thinking of original and imaginative educational tools such as new textbooks and online programs and resources. In addition, we should engage more broadly in special outreach programs such as visits to high schools to speak to young students and invitations to high school teachers and students to observe and train at universities and other institutions of higher education at the local, national, and international levels. Scientists should also reach out to explain their science through the media, something that is not done nearly enough today, especially by chemists.

Postdoctoral Training

A traditional and effective way to enhance the expertise of graduating Ph.D. chemistry students is through postdoctoral training. Such training may aim to sharpen or expand the knowledge and expertise of the student in neighboring or complementary fields, including those that were considered to be irrelevant to chemistry in the past. Examples may include, but are not limited to, fields within biology, medicine, physics, engineering, computing and modeling, communications, and business entrepreneurship. The global problems facing science and society today also provide guidance and inspiration for faculty to establish certain areas of research directed toward addressing the relevant challenges. Students should be encouraged to pursue postdoctoral training in such non-traditional, but critically important disciplines.

In addition to national centers of research, students should be encouraged to consider international institutions of higher learning for advanced studies in order to optimize their options for scientific and cultural enrichment. The latter is particularly important in an increasingly globalized environment where language skills and cultural understanding are often crucial advantages, if not requirements. While such postdoctoral studies were common (and still are, to some extent) among foreign students, who would travel to the US and parts of Europe to pursue advanced training, the reverse has been rather rare. This trend is likely to continue at some level (due to the desirability of such arrangements by both the hosts and the visitors), although funding constraints and fewer job opportunities in these countries may change the dynamics of the past to the detriment of both the US and the European countries involved and, of course, the students. Therefore, and in order to facilitate and expand postdoctoral training, additional postdoctoral fellowships should be established through special funding from the appropriate government agencies and philanthropic foundations from both recipient and despatching countries.

To diversify knowledge and skills, and therefore expand job opportunities for chemists, some students could consider the intriguing possibility of double graduate degrees along the lines of the M.D./Ph.D., which has been a successful program for highly qualified medical/biology students, at least in the US, for the last few decades. This paradigm could be recommended for qualified medical/chemistry students as well. Indeed, this M.D./Ph.D. combination, albeit rare, has already demonstrated its feasibility and worthiness. Chemistry students may also consider other combined Ph.D. programs, such as chemistry/biology and chemistry/physics degrees. Such combinations may also be pursued in sequence as post-baccalaureate or postdoctoral studies, and be expanded to include law or MBA degrees as a means to enrich one's professional skills and qualifications.

Creating and Disseminating Knowledge

The twentieth century has seen dramatic upheavals and changes not only in war and peace, but also in scientific, technological, and economic growth, as well as shifts in wealth. The origins of most of the latter developments can be traced to academic institutions that, through education and research, promoted discoveries and inventions which translated into wealth and prosperity, but also, at times, to destruction. A recent survey originating from Shanghai Jiao Tong University[6,7] of academic rankings of the world research universities placed 8 US institutions in the top 10 (the additional 2 from the UK) (Table 3). This is not an

Table 3: Top 10 Shanghai Jiao Tong University academic ranking of world universities, 2009.[6]

1.	Harvard University (US)
2.	Stanford University (US)
3.	University of California, Berkeley (US)
4.	University of Cambridge (UK)
5.	Massachusetts Institute of Technology (US)
6.	California Institute of Technology (US)
7.	Columbia University (US)
8.	Princeton University (US)
9.	University of Chicago (US)
10.	University of Oxford (UK)

accident, but rather a consequence of a number of converging forces that led to the great American university in the latter half of the last century.[8] The emergence of the American research university originated from European models, primarily the German, British, and French university systems, and gathered momentum in the 1930s and 1940s when waves of extraordinarily talented scientists fled Europe, particularly Germany, for the US that provided haven for them to create, disseminate, and apply knowledge. The striking successes of special projects during the war, such as the Manhattan and Penicillin Projects, and their impact on the outcome of the war gave a decisive impetus for the growth of the research university in the United States. Thus, and due to the efforts of strong visionaries such as presidential advisor Vannevar Bush, the architect of "Science The Endless Frontier,"[9] a new era for the American academy began. Through the establishment, soon after the war, of the National Science Foundation (NSF), the National Institutes of Health (NIH), and the funding mechanism from the Department of Defense, the government recognized the importance of academic research to the welfare of the nation, and thus fueled its growth. As a consequence of this commitment, a golden age for the American academy was witnessed in the last decades of the twentieth century with the so-called brain drain flowing primarily in one direction—from the rest of the world to the US. This astonishing success of investing in research universities brought with it unprecedented power and prosperity for the country in terms of economic wealth and international prestige. In order to ensure the maintenance and growth of these research universities and to catalyze the rise of others around the world, we must understand and appreciate the forces behind their success. These include a combination of the creation and dissemination of knowledge, autonomy and freedom of expression, meritocracy and tenure system, peer review system, and proper funding (endowments, philanthropy, federal and state funding) (Table 4). Moreover, American universities benefited from the abundance of opportunities for talented young people to pursue scientific careers in academia and industry in the US that led to the influx of some of the world's brightest students, scientists and engineers.

Table 4: Pillars of academic success of American universities.[8]

Combination of teaching and research
Autonomy and freedom of expression
Meritocracy and tenure system
Peer review system
Competition
Influx of talent from all over the world
Philanthropy
Federal and state funding

There are signs that these favorable conditions may be changing. For America to maintain its leadership in the world it must act now to halt and reverse these trends. This can only be achieved through the infusion of significant new funding in education and research, and by creating new opportunities for scientists and engineers to lead the charge into the new frontiers of science and technology. Given the finite amount of funds available, the US may need to reconsider its expenditures and reallocate funding from the sectors that currently enjoy higher priorities than science and education.[8] Other countries ought to do the same, for academic excellence is also increasingly becoming a matter of economic sustainability not only for these countries, but also for the academic institutions themselves.[10,11]

Foreign students have always been an important component of the student body of universities in developed countries. In recent decades this factor emerged stronger as the market for higher education expanded to include newly developed economies. The number of students attending higher education institutions outside their countries has tripled since 1980 to over 3 million. The top destinations of these foreign students are, in order of market share, the US, UK, Germany, France, Australia, and Canada, with the US commanding approximately 20% of the world market and Britain 12% (OECD figures, 2007).[10,11] The revenues generated from these students for Britain, for example, were an impressive US$39.4 billion in 2007. They come from all over the world and in increasing numbers from China and India where parents of new money send their sons and daughters abroad for the best education, preferably an Anglophone due to the emergence of English as the *lingua franca* of science, politics, business, and culture. Because foreign students pay top money for their tuition (as opposed to the internal students whose tuition fees are considerably lower and often subsidized by the government), they are a major contributor to the financial status of the host institutions. In addition, these students add decisively to the cultural enrichment of the institutions they attend. Furthermore, some of these talented students stay in the host countries, thereby contributing to the intellectual, technological, and economic growth of these nations. A good number of those who return home become ambassadors of good will for their host countries, and some even benefactors of their alma maters. All of these are good reasons why academic institutions and countries should strive for distinction in education and research, especially in the face of globalization and competition for the best and the brightest students. Traditional consumers like Singapore, Malaysia, and China are increasingly becoming providers as well, leading to an even more competitive race for the best and the brightest. The US has lost a significant market share in this race in the 5-year period leading to 2007,[10] a rather disturbing sign for the US institutions.

In response to the increased demand for higher education and the favorable economies abroad, a number of top universities in the developed countries moved to establish branches or partnerships with institutions in developing countries. New universities are also opening their doors in increasing numbers in places like the Middle East, Singapore, and China, where funding to build, equip, and staff them is readily available as these countries venture to become hubs of higher education and transform themselves into knowledge-based economies.

The Synergy and Dichotomy of Education and Research in Academia

Despite the successes of the "research university" this great American institution is not without its flaws. Its Achilles heel has recently been discussed by Savkar and Lokere. In their article titled, "Time to Decide",[12] they point out the ambivalence of the world of science toward education and urge the scientific community to place more emphasis on education than is currently practiced. Indeed, although academicians proclaim that education is equally important as research, they often devote most of their efforts and place more weight on research than they do on teaching. This is especially true in the most elite research universities and for the top research professors. This situation needs to be remedied for it does not serve optimally the mission of the university, which is both to generate and transmit knowledge. We have a responsibility to ensure a healthy pipeline of next generation scientists by passing to them the torch of knowledge more brilliant than we received it from our teachers, and the baton of the race for the quest of new knowledge.

There is no question that the forging together of education and research under the same roof has been critically instrumental in the emergence of the great research universities. Bridging the gap between teaching and research in these institutions can bring about even further improvements in education that will, no doubt, translate into still higher dividends for science and society. Several suggestions have been made toward this end.[12] I share the sentiment that a concerted effort is needed from various quarters, including faculty, university administrators, and funding agencies and foundations. Thus, professors should search their consciences and strive to be the best educators they can be; after all, this was most likely a major part of their motivation to enter the profession. Administrators should live up to what they preach by establishing ways to recognize outstanding teaching and financially reward those who perform at that level. Performance in teaching should carry more weight in decisions for tenure and promotions than it currently does, and more special awards for teaching should be established, and appropriately awarded and publicized. Such awards should be elevated to high prestige, comparable to those bestowed upon academics for research. Innovations in education should be encouraged and facilitated through more grants from funding institutions. A way to reward and recognize exceptional teachers, who may not be necessarily so productive in research, would be for departments to consider establishing tenure positions for them as "teaching faculty". If backed appropriately with rewards, all such recognitions will mean much more than just gestures; they will convey the message that education matters; and in the long run, it matters as much as research, if not more.

We should also recognize that faculty mentoring of students, is as important as parenting. In fact, in some cases, it turns out to be even more needed and decisive. Educators should, therefore, open their wings to embrace and share more of their time with students to provide guidance, support, and inspiration. In principle, senior faculty, including those with emeritus status, could be ideal mentors for both younger faculty and students. Indeed, some are, and admirably so, serving as role models and as inspiration to the younger generations.

Finally, government institutions, private foundations, and the media should devote more time and effort to science by informing the public of its importance to society and the young students of its excitement and rewards. We need to incentivize and motivate the brightest to enter into the world of science. Indeed, we ought to be doing this recruitment more systematically than we do now by identifying the most talented students as early as possible, preferably at the high school level, and mentoring them along their career paths with the same passion and enthusiasm as we pursue our own careers in education and science. Using the media to broaden the horizons of students will turn them into enthusiasts and open avenues for them to explore that they may not become aware of otherwise.

Conclusions

As devastating as they may be, crises often serve to awaken our instincts and strengthen our resolve to succeed as we regroup to respond and recover. The world is currently undergoing major changes, with some countries declining economically and technologically as others emerge. Change for the benefit of all mankind should be welcome as long as it is based on fair competition and responsibility. Indeed, this is a time for all nations to participate and cooperate as we all strive to provide solutions to the major global problems facing society and science today. Understanding nature through science is crucial to solving those problems. Education is the key to our destiny and that of our planet, for it is the mother of all that we create and transmit from generation to generation. Combining higher education and research under the same roof and the ability to attract the most talented students and scientists from all over the globe enabled the US to establish the greatest research universities in the world. These great universities also benefited from a number of other factors, unique mostly to the US, such as autonomy, meritocracy, philanthropy, and federal and state funding.

Indeed, the rise to preeminence is not necessarily confined to the American universities that benefited enormously from unique circumstances. The same conditions, if put in motion, could lead to similar successes in other parts of the world, especially as globalization makes the flow of information faster and more available to everyone. America, too, has new opportunities to benefit from abroad, as it did in the past, by learning from other cultures and understanding their needs and aspirations. To be sure, the US can benefit enormously by finding the will to adopt secondary education practices from countries that have proven themselves more successful in this respect. It is only a matter of will, but one of utmost importance for the country. Events in the last few years led to erosion in academic endowments, federal and state funding, and mobility of young students and scientists, all of which threaten the very foundation of the institutions of higher education and research in the United States and many other countries. If society is to continue to benefit from this great engine for prosperity, we must continue to nurture these academic institutions in order to ensure their vitality and growth not only in the US, but also in countries the world over. Higher education is becoming more global and therefore more competitive. The countries with the best institutions to educate the world will benefit the most by attracting and accommodating the best and the brightest students. This is the most noble international race in which we can participate as we travel the conduits of our destiny on this one planet that we share.

Academe alone, however, cannot solve the problems of the world. We need the cooperation of the policy makers, the finance and business world, and the public. Wise and courageous men and women from these institutions are the key to making the changes necessary for a new era. One of them is Peter G. Peterson, an American business man, politician, and philanthropist who in a recent speech to the American Academy of Arts and Sciences made the following remarks referring to the United States:

"*This is the first time in history that a majority of Americans do not believe their children will do better than they did. If they are correct, it will change this country at its core and what America has been all about. I am a great believer in the concept that an informed democracy is the best democracy. But* Americans *have been misinformed by politicians who believe that the American people cannot take the plain, hard truth*".[13]

As the central science, chemistry has a special role to play within these institutions, for it is both ubiquitous and enabling within the sciences, medicine, and engineering, all benefiting society through discoveries and inventions. Academics should, therefore, guard and continually invigorate chemical education, and education in general, not only to promote the science of chemistry and to prepare its practitioners to face today's challenges, but also to ensure its longevity and advancement.

During the last century and by relying on certain pillars, America led the way in establishing some of the great research universities in the world and benefited from the stockpile of knowledge they created, transmitted, and applied. Strengthening and sustaining these pillars is essential for the US to maintain its leadership, and for other countries to emerge as strong contenders in academic excellence. It is also essential for academics to preserve and uphold their freedom of thought and responsibilities as they attempt to contribute to the world through education and research. In this regard, Louis Menand said it best:

"*But at the end of this road there is a danger, which is that the culture of the university will become just an echo of the public culture. That would be a catastrophe. It is the academic's job in a free society to serve the public culture by asking questions the public doesn't want to ask, investigating subjects it cannot or will not investigate, and accommodating voices it fails or refuses to accommodate. Academics need to look to the world to see what kind of teaching and research needs to be done, and how to train and organize themselves to do it. But they need to ignore the world's demand that they reproduce its self-image*".[14]

And if academics have done their job right, they should be able to retire with the precious gift of satisfying content as John Pentland Mahaffy proclaimed he did in his time and space:

"*So now, when my part in the race is nearly run, there remains to me no higher earthly satisfaction than this, that I have carried the torch of Greek fire alight through a long life—no higher earthly hope than this, that I may pass that torch to others, who in their turn may keep it aflame with greater brilliancy perhaps, but not with more earnest devotion, 'in the Parliament of men, the Federation of the world'*."[1]

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[1] J. P. Mahaffy, *What Have the Greeks Done for Modern Civilisation*, Putnam, New York, **1910**, pp. 214–215, 246–247. This volume contains the Lowell Lectures delivered by the author in Boston at the invitation of the curator of the Lowell Institute in December and January 1908–09 "following many requests both from those that heard them and from those that did not". It is the most vivid and brilliant account of the subject that the author of this Essay has ever read. Mahaffy (1830–1919) was an Anglo-Irish scholar of the Classics, a philosopher, and a professor of ancient history at Trinity College, Dublin, where he eventually became provost. In addition to being a Hellenologist, he was an Egyptologist and had a doctorate in music. Among his most notable works are *History of Classical Greek Literature* (1903), *Social Life in Greece from Homer to Menander* (1903), and *The Silver Age of the Greek World* (1906). The colorful polymathic and eccentric life of this multitalented and brilliant scholar was marked with his sharp and famous wit. For example, when waiting to become the provost of Trinity College, Dublin, upon learning that the incumbent was ill, he is said to have remarked "Nothing trivial, I hope?".
[2] J. Buckingham, *Chasing the Molecule*, Sutton, Phoenix Mill, **2004**.
[3] A. J. Rocke, *Image & Reality*, The University of Chicago Press, Chicago, **2010**.
[4] Organization of Economic Co-operation and Development (OECD) Program for International Student Assessment (PISA) 2006, http://dx.doi.org/10.1787/141844475532.
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[6] "Academic Rankings of World Universities—2009", can be found under http://www.arwu.org/ARWU2009.jsp.
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[8] J. R. Cole, *The Great American University*, PublicAffairs, New York, **2009**.
[9] V. Bush, "Science the Endless Frontier", United States Government Printing Office, Washington, 1945, can be found under http://www.nsf.gov/od/lpa/nsf50/vbush1945.htm.
[10] "Foreign University Students, Will They Still Come?": *The Economist* **2010**, *396* (No.8694), 55–57.
[11] "Britain's Universities and Foreign Students, Hustling Spires": *The Economist* **2010**, *396* (No. 8694), 13.
[12] V. Savkar, J. Lokere: "Time to Decide", can be found at http://www.nature.com/scitable/forums/timetodecide, *Scitable by Nature Education* **2010**, Cambridge, Massachusetts.
[13] "The Education of an American Dreamer": P. G. Peterson, The *Bulletin of the American Academy of Arts and Sciences*, Summer 2010, *Vol. LXIII*, *No. 4*, p. 23–28. Also found online: http://www.amacad.org/publications/bulletin/summer2010/dreamer.pdf.

(*The Education of an American Dreamer*, Twelve, Hachette, New York, **2009**). Peterson is a son of Greek immigrants, co-founder of the Blackstone Group, and former Secretary of Commerce of the United States. Through a billion US dollar donation, he recently established the Peter G. Peterson Foundation, a philanthropic institution whose aim is to catalyze solutions to the daunting challenges, including education, facing America and the world today.

[14] L. Menand, *The Marketplace of Ideas*, Norton, New York, **2010**. Louis Menand is the Anne T. and Robert M. Bass Professor of English at Harvard University and author of *The Metaphysical Club*, which won the 2002 Pulitzer Prize in History. He has been a staff writer for the *New Yorker* since 2001.

