Science Education in American Undergraduate Institutions

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I. Introduction

After Michael Faraday discovered how to generate electricity in 1831, our human society has experienced drastic changes. In the twentieth century, science[1] and technology have played more important roles than those in the past century, when they were little related to common people's life. Nowadays, scientific terms such as the theory of general relativity, superconductors, and supernova appear quite often in everyday's newspaper. Moreover, used-to-be scientific terms such as atoms, molecules, transistors, lasers, genes, global warming, and nuclear powers, are not considered as purely scientific terminologies any longer. In fact, it would be difficult to imagine our modern life without such technological innovations.

America became one of the most important world leaders after the Second World War, and it has played a strong leadership for free democratic countries. Behind such a leadership, the science in the United States has played important roles. Big science projects, such as the Manhattan project, the Apollo project, and the Space Shuttle project, have attracted lots of attentions from all over the world and provided means to bring some scientific discoveries into real world apparatus. So, science is called the "Endless Frontier."

Why have American people been so successful in doing science during the second half of this century? In America, there are many creative scientists and skillful engineers, who are dedicated themselves to scientific and technological researches. There are lots of

1) The word of "science" is often used in two contexts: (a) any methodological activity, discipline, or study, and (b) the observation, identification, description, experimental investigation, and theoretical explanation of natural discipline, or study. In the first context, "science" includes the social science and humanities in a broader sense, but, in the second context, only the natural science is included. In this talk, the word of science in the second context will be used.

investments on scientific researches from government and industrial sectors. More importantly, there are a significant number of American publics who are supportive on various scientific activities and investments. In formation of the supportive general public group, I believe, the science education in America has played an important role.

In this talk, the science education in American undergraduate institutions will be discussed. However, it is difficult for me to present various aspects of the undergraduate science education in America. My knowledge on the topic is very limited. I did my graduate studies and postdoctoral works for seven years in the United States, but I was exposed to an undergraduate physics course only for one quarter while I was working as a teaching associate. Obviously, it was too short for me to get a big picture. In last June, I had a precious opportunity to visit several American postsecondary institutions and talk with science educators over there. After I came back to Korea, I read some articles and visited several interesting World Wide Web(WWW) sites related to science education. From these rather limited sources, my point of view on the science education in the United States was formed. And, it is this limited view that will be presented here today, so I beg your generous consideration on it.

II. Some Backgrounds

In the United States, there are various types of institutions: two-year community colleges, professional schools, and four-year universities. Depending on its type, each institution has different goals for the undergraduate education and different curricula to meet the goals. Most community colleges and some universities based on local communities (such as Roosevelt University at Chicago) try to provide broad opportunities of higher educations for the general public and open their doors to many local residents so they can take individual courses and programs. Since most students have part-time or full-time jobs in their work places, the education is usually focused on practical training in some specific fields. For example, an estimated 725 of American 1,325 two-year colleges offer engineering technology courses and about 500 of the two-year colleges offer science technology courses. After completing these courses, students are expected to move into their local communities as specialists. These institutions constitute a large portion of the postsecondary education in the United States, and it is desirable to look into the role of these institutions in more detail. However, in this talk, I want to focus on four-year universities which provides future leaders in American society with a broad general education that will lay a groundwork for their critical and creative thinking. Such an undergraduate education is often called a "liberal education."

The liberal education will help students to become knowledgeable about the world and the complexities of today's society. It also provides opportunities for students to be aware of moral, ethical, and social issues, and prepare intellectual leadership in a future. Instead of making students concentrate on topics in a specific area, it offers a broad education that will lay a durable foundation for critical and creative thinking. Eventually, it provides a solid basis for advanced scientific and scholarly researches, for subsequent trainings in the professions, and for ties of citizenship.

The science education in American undergraduate schools cannot be understood without considering the general infrastructure where the liberal education is performed. In many universities, natural science departments belong to the College of Arts and Science[2] with other departments of social sciences and humanities.[3] Under this integrated setting of various disciplines, students have a better chance for liberal education. They get introduction on substantive bodies of current knowledge in the natural sciences, social sciences, and humanities. They learn to understand and evaluate the sources and methods from which this knowledge derives, so they will be able to appreciate the contingency of all knowledge and to participate in ongoing excitements of intellectual discovery. They also develop communication skills that will enable them to join with others in the pursuit of common endeavors. Especially, they learn to write and speak effectively and to use another people's language as means of access to diverse contemporary and historical culture.

A student's emerging interests and talents find expression through an organized program of study in a major field. In the major program, students investigate the traditions and contemporary status of an established branch of knowledge. The deep structured study in one discipline complements the general exploration of our intellectual heritage, and provides the balance of educational breadth and depth. It should be emphasized that the undergraduate major programs under the liberal education are not

2) For some institutions, it is also called with different names, such as the "College of Letters and Science" or the "School of Arts and Science."

3) Some universities have several separate colleges. For example, University of Minnesota has three separate colleges(liberal arts, biological science, and sciences and engineering). And, arts and sciences at Ohio State University is divided into five colleges.

designed to produce professionally-trained specialists nor is it assumed that students will ultimately be employed in work related to the subject in which they are majoring.[4] Therefore, many American institutions place limits on their major programs. For example, Stanford University recommends its departments to develop well-structured major programs, each of which constitutes approximately one-third of a student's program.

American students have much flexibility to choose their major fields which fit to their interests and abilities. In most colleges, students who have interests in science enter the College of Arts and Science. In freshman and sophomore years, they get a broad education, including social sciences, humanities, English composition, foreign languages, mathematics as well as natural sciences. They usually have to determine their majors after a certain period of exposure to the broad human knowledge. For example, students at Columbia and Stanford will choose their majors after two years in colleges. Therefore, most American students do not have to make difficult decisions which might influence significantly their lives until they become juniors. It is also relatively easy for them to change their majors or to transfer to other colleges.

III. Science Education and Curricula

Just like in many other countries, most American science departments classify their students into three categories: non-science majors seeking scientific literacy, students in other science or technology-related programs, and students majoring in their programs. Depending on the nature of the student groups, they adopt different goals. The education for the non-science major students is organized to attract students in various academic fields and to increase science literacy among them. The education for the students in other science or technological fields is usually oriented to provide them with scientific fundamentals, so they can move into a variety of careers requiring a strong technical and scientific background. And, the educational goal for science majors is to produce a pool of students who are prepared to become first-rate research scientists.

Science education curricula and teaching methods for non-science major students should

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4) During the past decade, about one-third of all physics majors go to graduate school in physics, and another 20 percent go to graduate or professional school in some other area such as engineering, law, and medicine. And, about 40 percent obtain civilian sector jobs: 25 percent in industry, 11 percent with government agencies, 4 percent in high school teaching

be different from those for their counterparts. Generally speaking, it is difficult to teach non-science major students what scientist do, how they think, what kinds of questions they consider, what procedures they develop to evaluate the results of their research, and in what forms they present their knowledge. And, science educators in most countries are ignorant of the importance of the science education targeting non-science major students.

Just like in many other countries, most American college students outside the science-related fields are effectively scientifically illiterate. However, American science educators are more concerned with the education for such a group than the counterparts in other countries. They develop some introductory science curricula[5] which can be taught to non-science major students without relying on the calculus. Some science courses, such as introductory astronomy, are known to be quite appealing to many American students: astronomy courses draws more than 200,000 students throughout the Unites States each year. American educators are also trying to attract students for some interdisciplinary courses on science and humanities.[6] Such introductory and interdisciplinary courses targeting for non-science majors, I think, will make contributions on forming citizen groups who will support science and technical programs. It also enhances communication and understanding between citizens and technical experts on some important issues such as global environment and nuclear wastes.

Now, let us look into the education for students studying in science-related fields, such as physical sciences, engineering, and premedical and biological sciences. As mentioned earlier, many American students decide their majors after two years in colleges, so many science courses in the first and second years are targeting for students who have general interests in the science-related fields. These introductory courses are supposed to provide individuals with a variety of science and mathematics fundamentals which underlie many

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5) The National Science Foundation(NSF) WWW site show an interesting list of science curricula targeting non-science majors. The list includes "Conceptual Astronomy: A Process Oriented Course (University of New Mexico)," "Workshop Biology for Non-Majors: Promoting Scientific Literacy (University of Oregon)," "Introductory Laboratory Program in Chemistry: Focus on Attitudes (State University of New York– Stony Brook)," and "Physics for Poets" (University of Wisconsin).

6) NSF Division of Undergraduate Education provides grants for developing interdisciplinary courses on science and humanities. A partial list of proposals which received 1993 grants includes "Darwin and Darwinism: Science Theory and Social Construction, the Undergraduate," "Society, Ethics, and Technology: An Interdisciplinary, Core, General Education Course," "New Perspectives: Humanities and Sciences," and "Integrated Course in Science and Humanities for Elementary Education Majors."

technical fields of modern complex societies. Some introductory courses are organized for students who did not learn much calculus at high school, but it is expected that most students in the science and technological fields will eventually have good mathematical capabilities before leaving colleges.

Teaching these introductory courses is one of the major responsibilities for many science departments, so they usually hire a large number of faculty members and teaching associates and work with a huge budget. Due to the high demand of such introductory science courses, a typical size of a class is rather large: for instance, some introductory physics or chemistry classes are composed of more than 200 students. To provide more attention to students, several recitation or tutorial classes for a small group of students (such as 10–30 students per a class) are taught in parallel by teaching associates. And, these introductory science courses usually accompany laboratory classes, so students will be able to acquire better understandings on natural phenomena by doing several table-top experiments. Laboratory classes are taught by another group of teaching associates with the help of professors, laboratory managers, and technicians. Therefore, it is not easy for a department to organize and manage such large-scale introductory courses successfully.

On the other hand, the introductory courses are very important opportunities for the science educators to attract good students in their academic fields. Under the system where the students have a freedom to choose their majors after exposing themselves in various fields, there will be a strong competition among departments to recruit high quality students. Many departments usually assign their best teachers to the introductory science classes and provide various supports (such as interesting lecture demonstrations, excellent modern laboratory equipments, and access to computer facilities) for their future major students. Of course, it is the students who will get the most benefits out of this system.

Most science courses for major programs are organized for a small group of students. One of the interesting facts on the science major courses is that they are built in a highly sequential manner on some introductory courses. In many cases, students must take the introductory courses early in their college careers in order to get their bachelors degrees in four years, though they need not declare their major until later. Therefore, in most university, several introductory courses in different science sectors are required as degree requirements for students in science related fields. For examples, MIT requires all of its students to take at least two courses on calculus, two courses on physics, and one course on chemistry.

Except in a few field such as astronomy, there is remarkable uniformity in the curricula of undergraduate science major programs in the United States.[7] One- or two-year introductory courses survey some important basic subjects, most of whose roots lie in the discoveries of the late nineteenth and early twentieth centuries. Then, students should take more additional major courses, which constitute 25 to 35 percent of the credits for the degree. The structure of some science curricula is often referred to as a spiral. Several core subjects are revisited at least twice and often a third time in the elective and specialty courses. Each course in the sequence is necessary for courses at the next level. The intermediate and advanced courses address the core subjects with increasing conceptual complexity and mathematical sophistication, synthesizing from all that have gone before.

Some students in major programs have opportunities to work independently or as part of a team on projects ranging from writing preliminary research designs to carrying out sophisticated research projects. For example, the Undergraduate Research Apprentice Program at University of California at Berkeley allows students to work on a one-on-one basis with faculty engaged in advanced research. Students who apply and are selected for the program receive close mentoring and the opportunity to work with the ground-breaking faculty. These science project programs provide some talented undergraduate students with chances to participate early in research activities.

IV. Lecture Demonstrations and Laboratory Experiments for Science Education

Direct experience with natural phenomena is an essential part of learning science. Science inherently involves observation, measurement, modeling, and abstraction of the natural world. For most science topics, just learning from a classroom using simple models and theories might not be good enough. To fill the gaps between classroom teaching and real worlds, many United State institutions utilize lecture demonstrations and laboratory experiments. The success of the science education in the United State in bringing forth talented scientists, I believe, is rooted in the excellent management of these forms of education.

7) Actually, the curricular uniformity in science does exists not only in the United States but around the world.

Lecture demonstration is useful for students to see what happens in a real world and how to apply the knowledge of simple models and theories to real natural phenomena. It also help teachers to attract students attention from boring lectures and excite their interests for natural phenomena. Therefore, in many science classes, lecture demonstrations are used once or twice a week. Various lecture demonstrations are performed using simple kits and other audio-visual equipments. For example, the Physics Lecture Demonstrations Collection, University of California, Berkeley, is comprised of over 1,000 pieces of equipments, plus 50 film strips (3-4 minutes each), 20 films (approximately 1 hour each) and 100 videotapes of seminars and colloquia. There are usually a separate storage area for the demonstration collection near lecture rooms. Many science departments hire special managers who take care of the collections and/or actually perform lecture demonstration in front of students, so professor can ask help from them on a weakly basis.

Laboratory experiments are another suitable way to form the basis of organized experience upon which students can test models and explanations of nature. A typical number of students in a laboratory course is small (i.e., between 10 and 30 students). In the elementary level, they participate in a series of designed experiments under the guidance of one or two teaching associates following a written procedure in a manual. In the advanced level, students are asked to design and perform their own experiments, which might need more complicated equipments, skills, and conceptual knowledge under the guidance of professors and teaching associates. Students will measure and record experimental data, perform data analysis on them, and compare those results with what they learn in a classroom. They will appreciate that there always is an imperfect match between theories and the real world, partly due to the measurement errors and (more importantly) incompleteness of the theories. The ability to realize the incompleteness and the desire to get a better explanation will make students become leading scientists. Therefore, the importance of the laboratory experiments cannot be overemphasized.

Why are American undergraduate institutions are successful in the education based on laboratory experiments? The answer might be in the infrastructure of the American institutions, such as proper management personnel and numerous supporting facilities. In most universities, various types of personnel are participating in laboratory educations; professors, teaching associates, and laboratory technicians. Professors set up goals of a laboratory course, select a proper sequence of experiments, educate teaching associates, and arrange proper financial and technical supports. Teaching associates, who are usually graduate students, teach students how to handle equipments and take the data. They help students to learn how to analyze the data under the context of basic principles, evaluate the error, and find the sources of error. They also help professors in evaluating the performance of students. Laboratory technicians take responsibilities of setting up laboratory apparatus, supplying parts, and repairing broken equipments. They are sometimes involved with a project for designing new experiments and developing new apparatus.

Compared to their counterparts in other countries, the teaching load of these laboratory personnel in American universities is remarkably weak, so they are able to concentrate on their teaching in the laboratory. For example, in the "Advanced Experimental Physics (PHYS 510)" course at Cornell University, there are forty to fifty students enrolled per semester. Five or six professors are assigned to the laboratory course, and it the only teaching load for the professors. Moreover, most personnel have a good background to understand what is taught in the laboratory class. In most universities which I visited during last June, science departments have a staff of proficient technicians for laboratory education. For instance, Department of Chemistry, University of Wisconsin, has a couple of Ph.D.'s and some college graduates as laboratory technicians. The devoted works of these highly educated personnel make it possible to provide a good laboratory education for students.

V. New Developments

The world is changing. More than ever before, science and technology play an important role in various areas, such as food, health care, consumer electronics, airports, and hazardous waste disposal. Moreover, we are experiencing dramatic changes in the computer and telecommunication areas. Under these circumstances, the basic aptitude of students entering in colleges are also changing. Nowadays, many students have been exposed to computers since they were young. Since learning computer is typically an inductive process, most of recent college incomers are good at learning new ideas by inductive reasoning. However, most of current science educations and curricula are based on deductive reasoning, which has been considered the most essential component of scientific thinking. Therefore, it is necessary to develop new science curricula for the students with this new background.

During my visit to the United States, many professors expressed the need for curricular reform in science education. A number of professional societies have already begun to explore new approaches to science education and curricular reform. For example, the American Mathematical Society focused a society-wide effort on developing alternative approaches to undergraduate calculus reform, which resulted in the development of a selection of new calculus textbook. The American Chemical Society has initiated society-wide examination of issues related to the importance of developing new approaches to undergraduate education. The American Institute of Physics has recently begun debating the nature and content of undergraduate and graduate physics programs and will be convening meeting on this subject in the coming year. And, the American Astronomical Society has began the AAS Education Initiative to identify specific changes in curricular goals for undergraduate and graduate astronomy education in the 21st century. Behind such organizational efforts for curricular reform, the Division of Undergraduate Education, National Science Foundation, provides financial supports through projects and leadership activities.

The curricular reform, organized by professors at the Department of Chemistry, University of Wisconsin, gave me deep impression during my visit in last June. The Institute of Chemical Education was developing new curricula of introductory chemistry courses based on a new paradigm, called the "topic-oriented education". To meet interests of enrolled students in introductory chemistry courses, they choose some specific topics and teach the chemical concepts using such topics. For instance, for students from material science and electrical engineering backgrounds, they teach various chemical aspects of semiconductors, ceramics, and so on. Instead of making students tired by teaching difficult and purely abstract chemical concepts, they try to attract students attention by starting from well-known examples and provide students motivations for the new knowledge. To my impression, this new approach in science education will be very useful for many students.

There are another developments which are worthwhile to note. Computer starts to enter science education in various ways: searching for literature in a library, taking data in laboratory courses, simulation demonstration in a lecture room, and so on. Especially, communication using computer networks, such as Internet, becomes very popular among young generation. Nowadays, many science departments are trying to use such networks as means of educational tools. Some teachers puts some teaching materials and homeworks in a certain site of a network, so students can access to it freely any time they wants. Moreover, students can ask questions and make to their teachers using the network. At present, more than 400 United States universities open the World Wide Web sites, and the number is increasing drastically. Especially, many science educators are actively participated in this new form of education using the modern technology. This development will be more widespread in a near future and provide a significant impact on the science and technological educations.

VI. Problems

The science education in the United States has enjoyed much success during the last several decades, and many educators in other countries have tried to copy the American system. That is the one of the reasons why some science curricula in many countries are remarkably uniform. However, there is no system which is perfect. In the American undergraduate education, there are also symptoms of problems, most of which are related to recent changes. It is quite worrisome since the new problems seem to start corroding the basis of the liberal education, and since many other countries would follow the American case.

As the knowledge of one science discipline increases drastically, many major programs become more demanding. Nowadays, most departments give a higher priority to graduate training and undergraduate majors than to general (pre-major) education. Even though there are some efforts to provide improved coordination and academic support services for the general education curriculum, such efforts lack sufficient resources and institutional supports. This phenomenon is well expressed in a recent report:[8]

> "Much of our education is fragmented among colleges, schools, and departments. With the increasing number of courses, students are staying longer and longer and may be learning more specific knowledge, but at the expense of a general understanding of the humanities, law, social sciences, and natural sciences. Pinnacle learning with increasing gaps between the peaks is becoming a hallmark of graduate education and is eroding undergraduate education."

One important issue related to this problem is the time for choosing specialized fields in

8) "Planning for the Future of the University of Washington: Issues and Recommendations," 1994.

one discipline. For some areas such as mathematics and physics, a broad view of the disciplines is more emphasized than a specialized concentration. In such fields, specialization begins practically only after the second year of graduate study, and any pressure for early specialization in undergraduate curricula is deferred. However, for some fields such as chemistry and biology, students are urged to choose specialized fields or at least to find interested fields before leaving their undergraduate school. For example, Department of Biology at MIT asked students to choose their fields of specialization, as soon as they enter their graduate programs. This kind of academic culture tacitly discredits or actively discourages talented students from entering other areas. And, the color of the liberal education would be tarnished.

Separation between scientific research and science education has come to many of American universities. Nowadays, the success in science is frequently measured only by an individual's contribution to advancing research frontiers, and the contributions to good undergraduate education are considered useless. One of the sources for this problem is the rewarding system in the American universities. In the atmosphere of publish or perish in many prestigious universities, professors are supposed to spend more time on researches and teaching graduate students. The reputation of being a good teacher in undergraduate courses does not help much for them to get tenure or honor. Therefore, they do not pay much attention to undergraduate courses any longer, and excitements of new science discoveries rarely come to undergraduate classes.

The recent decrease of federal supports on basic scientific research hurts American science education in numerous ways. Due to the lack of research money for basic science, many professors started to concentrate on applied science or technological fields rather than purely scientific issues. And, they have to spend more time in finding resources and getting research grants, so spending their precious time on undergraduate education seems to be hopeless for them. Moreover, the job market for recent graduates in some science fields becomes gloomier than before. Due to this dark perspective, many talented students are leaving science, and many science departments fail to recruit high quality students. Some people said that the demise of the era of the "Endless Frontier" is just around the corner. Even though the pessimistic view emphasizes on the dark too much, the situation will become obviously inadequate for us to prepare a future society based on science and technology.

VII. Summary

The science education in American undergraduate institutions can be characterized as one means of the *liberal education* for students who are interested in science and its related fields. Instead of teaching the specific techniques and detailed knowledge in one scientific area, American educators put a strong emphasis on critical and creative thinking which form the basis of science. This undergraduate education helps American students to critically review the current status of a knowledge and find new ingenious methods to attack problems when they become experts. These activities in their professions eventually have contributed in maintaining and advancing the United State leadership in science research.

Another characteristic of the American science education is the strong emphasis and solid supports for the *laboratory education*. Science cannot be learned without direct experience with natural phenomena. Due to the strong financial and personnel supports in most American undergraduate institutions, students have genuine opportunities to test the models which they learn in classroom and appreciate the differences between theories and the real world. This laboratory education provides students with an abilities to look at the world as it is.

More than ever before, science and technology play an important role in the society. And we are moving into a future in which the human society will be ever more dependent on a population with a working knowledge of science, so we have to educate more people who are creative and scientifically literate. Many people agree that the American science education is the best in the world in producing students with creative minds. It is one of the driving forces for America to play leading roles in world communities. Science educators in many countries have tried to copy the American curricula for teaching their students, but they cannot get the same amount of success which the American counterparts enjoy. Learning a formalism without understanding the essence is useless. Therefore, it is important for us to understand important aspects and general backgrounds of the science education in America, and to develop our own programs which are the most suitable for our students.

The world is changing and so must our science education. Especially, the recent developments in the telecommunication area might change our school system based on the classroom lecture into that on computer networks, and it is difficult for us to predict the proper teaching methods in such computer-based society. With this uncertainty, we have to reform the science education. This is a quite challenging job for science educators all over the world, including American teachers.