CLASSICS

A Brief Introduction to the Topic of the Classics Note by Freeman Dyson*

This is the content of the acceptance speech delivered by Dyson on being awarded the 1991 Oersted Medal by the AAPT. Dyson who has extensively spoken and written critically earlier on science teaching in schools, explains his reasons for advocating teaching 'less' science in classrooms. He encourages an environment like museums and public libraries for children who "learn better on their feet than on their behinds." At one point, while talking about higher education he says, "I would like to give everybody a PhD at birth, or on the day they enter Graduate School, so that the PhD would no longer be an obstacle either to education or to scientific employment." Towards the end of his speech, he says somewhat provocatively, "If science ceases to be a rebellion against authority, then it does not deserve the talents of our brightest kids."

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"To teach or not to teach," Freeman J. Dyson's acceptance speech for the 1991 Oersted Medal presented by the American Association of Physics Teachers, 22 January 1991

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I. THE VIEW FROM ENGLAND

Thank you, not only for the medal, but for the invitation to come to your meeting and learn about all the fine things the AAPT is doing. Your meeting is far more lively than most of the meetings I go to.

I find it absurd that I should have been chosen to receive this honor. The Oersted was one medal that I was sure I would never get. When I look around, among all my friends there is nobody who does less teaching than I do. There is nobody who deserves this medal less than I do. I was glad to see that you gave a Distinguished Service Citation this afternoon to Yvette van Hise. She earned it the hard way, by actually teaching. If there were any justice in this world, she should have been standing here in my place. I hope one day she will. I have not taught a serious physics course for 15 years. I have not had a job with a regular teaching load for 35 years. I have been leading a care-free parasitic life, or more accurately a saprophytic life, for all these years, while you in the audience have been laboring in the classroom. A parasite is somebody who feeds on the living, while a saprophyte is somebody who feeds on the dead. At the Institute for Advanced Study where I work, we live on money given to the Institute by Louis Bamberger and Mrs. Fuld 60 years ago. We are saprophytes rather than parasites. Whatever teaching we may do is done voluntarily, without the unpleasantnesses of setting exams and assigning grades. Standing here in front of an audience of real teachers, I am overcome by feelings of humility. Humility is not usually my strong suit. But today I am genuinely grateful and genuinely humble.

I feel humble, not only because I have done little teaching myself, but also because I have on various occasions pontificated about education, taking a negative view of the educational establishment. In spite of my critical attitude toward teaching, you have honored me with your medal. So I will try to explain honestly why I am critical of the educational enterprise, and why I nevertheless deeply respect the individual teachers who are engaged in it.

A year and a half ago, I gave an after-dinner talk at Yale University on the occasion of the 150th birthday of Josiah Willard Gibbs.[1] Since I was talking in a relaxed mood at the end of a strenuous day, I took the opportunity to be provocative. I was trying to keep a tired and well-fed audience from falling asleep. I said it was lucky that Willard Gibbs was not taught physics in school. I said the reason he did so well as a creative physicist was that he spent most of his classroom hours learning Latin. I was pricking the sacred cows of the science education establishment and challenging the accepted wisdom.

After I came back to Princeton from Yale, my friend the physicist Chiara Nappi gave me the text of a different talk about science education. Her talk was published in abbreviated form in the May 1990 issue of Physics Today.[2] I recommend that anybody who has not already read Nappi's statement should read it. It is full of good sense, and it is saying things that had not been said before. I myself found Nappi's statement completely convincing. Everything she says in the statement is true. There is only one little problem. The things Nappi says in her statement are diametrically opposite to the things I said in my talk at Yale. She says the kids need to be taught more science in schools. I said they need to be taught less. How can we both be right?

My task this afternoon is to explain how it can happen that two opposite statements can both be true. The key to the explanation is Niels Bohr's principle of complementarity, which Bohr liked to apply to situations in ethics and philosophy as well as in physics. Complementarity says that nature is too subtle to be described from any single point of view. To obtain an adequate description, you have to look at things from several points of view, even though the different viewpoints are incompatible and cannot be viewed simultaneously. Statements that are true when seen from one point of view may be false when seen from another. There is no logical contradiction here, because the behavior of the object you are observing changes as you change your point of view. Here is a quotation from Niels Bohr himself:[3]

"In the Institute in Copenhagen, we used often to comfort ourselves with jokes, among them the old saying of the two kinds of truth. To the one kind belong statements so simple and clear that the opposite assertion obviously could not be defended. The other kind, the so-called "deep truths," are statements in which the opposite also contains deep truth."

The minds of children, and the interactions between children and teachers, are subtle and dynamic enough so that deep truth can be expected to prevail. We may be surprised by Bohr's assertion that the principle of complementarity applies to an object as simple as an electron. We have no reason to be surprised by the discovery that the principle applies to something as complicated as a child. I propose now to put my Yale talk and Nappi's article side by side, to see how they can both be true.

Chiara Nappi and I are both immigrants in America, she from Italy, I from England. Both of us base our arguments on childhood experiences that we brought from our homelands. It is not surprising that the viewpoints of an Italian child and an English child are complementary. You cannot look through Italian and English eyes simultaneously. Here, first, is my view of science education, seen through English eyes.

Throughout the 19th century and the first quarter of the 20th, very little science was taught in English schools. This began to change in the 1920's and 1930's. Various committees of learned men declared that the English were a nation of scientific illiterates and that something had to be done about it. What had to be done, of course, was to push Latin

and Greek out of the schools and bring in science. I was lucky. When I was half-way through high school the war began and the system began to fall apart. In my last year of high school I spent a total of 7 hours a week in class. That was the best time I could have chosen to get an education. After the war was over, the teachers came back and the system was tightened up, and now nobody dreams any more of spending 7 hours a week in class. Now the kids are kept chained to their desks and are pumped full of predigested science, just as they are in America.

If you look back and see what effect the reform of the schools had on the output of science in England, you can see that the effect was substantial. All through the 19th century and well into the 20th, so long as the schools were heavily concentrated on Latin and Greek, England produced an amazing number of first-rate scientists, Darwin, Faraday, Maxwell, Joule, Kelvin, Dirac, Crick, and so on. You don't need to count up the number of Nobel Prizes to prove that England was doing well. It is more difficult to make an objective assessment of science in England during the later period, beginning about 1950, since all young scientists have had to go through O levels and A levels, which are the English jargon words for a formal scientific education. A lot of the younger English scientists are good, but I see only one, Stephen Hawking, that I would put in the same class with Maxwell and Dirac. Somehow or other, the shift in the schools from Latin and Greek to physics and chemistry has been successful in keeping the most original minds away from science.

We all know that the decisive years for turning young minds away from science are the years before they reach high school. The damage is mostly done in elementary and middle schools. Again, I use my own experience to show how apparently unfavorable circumstances may lead to favorable results. Here is what happened to me. I spent the years from 8 to 12 at an establishment known in England as a Prep School, which corresponds roughly to what we call in America a Middle School. The school did not teach any science. The wave of reform, which by that time had begun to introduce serious science teaching into the high schools, had not yet penetrated down to the Prep Schools. At the Prep School we were still taught the classical 19th-century curriculum, lots of Latin, a good deal of mathematics, no science. The school was similar to that splendid educational institution Dotheboys Hall, as Dickens describes it in his novel *Nicholas Nickleby*. The headmaster was a sadist who reserved for himself the pleasure of teaching Latin to the upper forms. His method of teaching was to keep a riding whip handy and apply it zealously to anybody who made mistakes in grammar. Since I was rather good at Latin grammar, I mostly escaped the whip. So far as I was concerned, the cruelty of the headmaster was less oppressive than the brutality of the boys. The boys were at their most barbarous age, and they redressed the balance of injustice by torturing those who had escaped whipping. Their favorite instrument of torture, sandpaper applied to the face or to other tender areas of skin, was more to be feared than the headmaster's whip.

So it happened that I belonged to a small minority of boys who were lacking in physical strength and athletic prowess, interested in other things besides football, and squeezed between the twin oppressions of whip and sandpaper. We hated the headmaster with his Latin grammar and we hated even more the boys with their empty football heads. So what could the poor helpless minority of intellectuals, later and in another country to be known as nerds, do to defend ourselves? We found our refuge in a territory that was equally inaccessible to our Latin-obsessed headmaster and to our football-obsessed school mates. We found our refuge in science. With no help from the school authorities, we founded a Science Society. As a persecuted minority we kept a low profile. We held our meetings quietly and inconspicuously. We couldn't do any real experiments. All we could do was share books and explain to each other what we didn't understand. But we learned a lot. Above all, we learned those lessons that can never be taught by formal courses of instruction, that science is a conspiracy of brains against ignorance, that science is a revenge of victims against oppressors, that science is a territory of freedom and friendship in the midst of tyranny and hatred.

Perhaps my experience in that Prep School between the ages of 8 and 12 was not exceptional. Perhaps there were others in similar circumstances who found in science a beacon of freedom and hope. Perhaps that is why, during all those years when the schools were teaching Latin and Greek and totally neglecting science, England produced so few great classical scholars and so many great scientists.

II. THE VIEW FROM ITALY

That is enough about England. Now let us hear what Nappi[2] has to say about the teaching of science in Italy.

"The approach in Europe is more systematic and steady in math and science, as in all other subjects. Students start studying math and science at an earlier age and proceed through high school at a more relaxed pace. In the lower grades, while basic math and problem-solving skills are mastered, concepts of higher-order mathematics are also introduced. In high school, there are no crash courses. For example, most American high school students study algebra intensively for a whole year, with daily classes on the subject, only to drop it the following year to concentrate on another subject, such as geometry, for another intense full year. But in Europe these subjects are studied in parallel over several years. Likewise, the physics that American students are supposed to learn in a year is spread over three or four years in Europe. Concepts in math and science need to be assimilated, and that takes time. European high school students study physics, chemistry, biology and mathematics every year. The amount that they study varies from one type of high school to another, but they all must take these subjects every year.

"The point I want to make is the following: (here, Nappi prints her message in italics). If courses are unnecessarily tough, and moreover optional, students do tend to opt out. The teenage years are particularly critical. Boys and girls undergo so many physical and emotional changes that it is unwise to place too much pressure on them then. It is the time when gender roles and stereotypes really sink in. Especially in the United States, there is a great deal of pressure on girls to concentrate on being socially successful. It is well known that these problems start in high school and that there is no significant difference between boys' and girls' performances in math and science up to eighth grade. Further, girls in European high schools do seem to perform better than their American counterparts. It is not that stereotypes or gender roles do not exist in Europe. They do. However, in more structured educational systems like those in Europe, there is much less room for stereotypes to have an effect. No matter how you envision your role in life,

you still need to know a required amount of math and science before you get out of high school. And because courses are not made unnecessarily intense and demanding in European schools, all students can handle them better, in spite of some inevitable teenage crises.

"The American educational system is actually very selective. It selects the very talented and self-motivated students, those who would do well in any system. It does not give a fair chance to the others; it simply neglects them. An educational approach based on difficult and elective courses tends to discriminate against lower-class children, who often do not have the supportive home environment that would channel them toward math and science and help them through these subjects. In Italy the same curriculum is used all over the country. Children of the same age study the same topics in all subjects at about the same time. The Italian system has proved to be a powerful social equalizer. During the course of one generation, it has leveled enormous cultural differences between north and south, men and women. A national curriculum has the advantage that results do not depend too heavily on the particular geographical area, school district or even the teachers' level of competence.

"In conclusion, US students' performance in math and science could be highly improved by a more systematic approach to math and science teaching. One of the main problems at the moment is that US schools start teaching math and science too late, and therefore much too fast, with the result that teenagers are driven away from the optional math and science courses. This approach hurts everyone, but its most serious impact is on women and minorities. A change would represent an important step toward equality in education and society."

I apologize to Chiara Nappi for squeezing her eloquence down to a few abbreviated paragraphs. I hope that next year you might invite her to your meeting to speak for herself. She can tell you of the shock she experienced when she came to the United States and everybody asked her how it happened that she became a professional physicist in spite of being a woman. In Italy this question did not arise, because girls and boys alike were exposed to physics, whether or not they liked it, and those who liked physics tended naturally to become physicists, whether or not they happened to be women. To be a woman physicist in Italy is, as Nappi says, no big deal. Her message to the United States, based on her Italian experience, is that formal education in science can be effective and can reach children at all levels of society, provided only that it is begun early and continued steadily through 12 years of schooling. My message is the opposite. I am saying that I was lucky not to be taught much science in school, that formal instruction in science is counterproductive, that a heavy science curriculum turns off more kids than it turns on. I am saying that if you want to turn children into scientists you must let them experience science as an escape from tyranny and not as another form of tyranny.

How can Nappi and I both be right? Here we must go back to Niels Bohr and the lessons of complementarity. Nappi is right when she says that science, impartially imposed on children by a centralized educational authority, can be a powerful force working for social justice and equality of opportunity, as it is in Italy. I am right when I say that a minority of children set free from the slavery of the class room, as we were in war-time England, will pursue science with a passionate enthusiasm that a class of school-trained examination passers cannot match. We can both be right, because we belong to different cultures and we are speaking about different kinds of children. There is no such thing as a child in the abstract. There are only particular children, all of them different. Nappi's prescriptions are good for the great mass of children, mine are good for the élite. Hers are good for the law-abiding majority, mine are good for the rebels and outlaws. But it is not possible to divide children into a docile majority and a rebellious minority and deal with them separately. Each individual child, like each individual electron, has complementary qualities of docility and rebelliousness. Each child needs both discipline and freedom. Discipline and freedom are, like position and momentum, complementary aspects of education that are both essential. Somehow or other, teachers have to supply both. That is the true vocation of a teacher, to start all the children learning with an equal dose of discipline, and then to know when it is time for discipline to stop and freedom to begin. That is a difficult, almost an impossible, vocation. That is why teachers deserve our deep respect.

III. THE PROBLEM OF THE Ph.D.

I have been talking so far about elementary and high-school teaching. Probably most of you in the audience are teaching in colleges and universities. Most of what I said about schools applies also to higher education. The dilemmas that we encounter in the high schools reappear in a similar form in colleges and graduate schools. We have again a clash of cultures, with Nappi upholding the virtues of the traditional European Ph.D. system while I am trying to destroy it. And again, both of us are right. The virtues of the Ph.D. system are real. It was invented in Germany as a way of giving official status to young people who wished to dedicate their lives to scholarly pursuits. The system worked well in 19th-century Germany and made the German universities into models for the rest of the world and especially the United States to copy. The system worked well so long as the students were few in number, talented enough to do genuinely original research, and intending to make careers in academic institutions. The system still works well for the minority of students who are, like the German students of a century ago, budding Professors or budding Nobel-prize winners. But the system does not work well for the majority of students in America today. A recent article by Susan Coyle,[4] with the title "The Long Haul to a Doctorate," explains why the system is failing. Students spend far too many years in school before they are finished. The average student emerges at the end of the Ph.D. program, already middle aged, over-specialized, and poorly prepared for the world outside, almost unemployable except in a narrow area of specialization. Large numbers of students for whom the program is inappropriate are trapped in it, because the Ph.D. has become a union card required for entry into the scientific job market. I am personally acquainted with several cases of young people who became mentally deranged, not to speak of many more who became depressed and discouraged, their lives ruined by the tyranny of the Ph.D. system. It is no wonder that most of the best and the brightest of our young people, including my own daughters, decided to stay out of the trap. And unfortunately, now that the Ph.D. has become a union card for scientists, staying out of the trap means staying out of the scientific profession.

I was lucky, growing up in England at a time when the Ph.D. was not yet obligatory. Many of the leading scientists in England, like the surgeons, took pride in calling themselves Mister rather than Doctor. Soon after I left, the Ph.D. system tightened its grip on England as it did earlier on America. I have been fighting the system in America for 40 years, with absolutely no success. Nobody comes now to work at the Institute for Advanced Study, as George Kennan and I did in the good old days, with only a Bachelor's degree.

Politicians and business leaders are wondering why American graduate schools are filled with foreign students and not with Americans. Susan Coyle[4] answers their question. "Getting a doctorate takes about seven years, followed by up to three years in a postdoctoral appointment. For students, this means more debt, less income and perhaps postponing the start of a family." For the rare spirits who are genuinely in love with science, a seven-year vow of poverty may not be a deterrent. For ordinary bright Americans who are choosing a career, the deterrent is strong enough to keep most of them out of science.

What can we do to limit the damage that the Ph.D. system is doing to our young people? Our problem is in many ways similar to a problem that existed in England a hundred years ago. At that time in England, the Mathematical Tripos examination distorted the whole structure of mathematical education. The Tripos was an absurd and artificial contest that gave the students no exposure to modern mathematical ideas and little incentive to try their hand at research. The Tripos system, in the opinion of my teacher Professor G. H. Hardy, set back the progress of mathematics in England by about a century. When Hardy came to Cambridge as a young radical, he decided that the only way to save English mathematics was to abolish the Tripos completely. But he soon found out that his attempts to abolish the Tripos united against him all the vested interests of Cambridge, with the result that even modest reform of the system was stymied. Hardy then changed his tactics. Instead of trying to abolish the Tripos, he started a campaign to trivialize it. Trivializing the Tripos meant making it so easy that students could get it out of the way and still have time to go on and learn some real mathematics. The decisive step was to forbid any public announcement of the Tripos order of merit, so that the students were no longer competing like race horses for the position of Senior Wrangler. The tactic of trivialization achieved most of Hardy's objectives, although Hardy himself remained sorry that the Tripos virus remained alive in attenuated form. He remained to the end of his life an abolitionist.

I am saying that the Ph.D. system is distorting and damaging American science today, just as badly as the old Tripos was distorting English mathematics a hundred years ago. And, like Hardy, I have had to recognize that abolition is politically impossible. Too many vested interests are entrenched in the system. The best we can hope for is to trivialize the Ph.D. as Cambridge trivialized the Tripos. I would like to give everybody a Ph.D. at birth, or on the day they enter Graduate school, so that the Ph.D. would no longer be an obstacle either to education or to scientific employment. If such a rational solution of the problem is judged to be too radical, we could envisage a compromise solution in which the time required to obtain a Ph.D. is drastically shortened. At the very least, we could make sitting through graduate courses and writing a thesis alternative options, instead of requiring every student to do both. The time it would take to finish the degree would then be roughly cut in half, and the damage to the students reduced in proportion. Some students need formal course work. Others do not. Some students are capable of significant original research. Others are not. It is cruel and destructive to force them all into the same mold. My favorite poet, William Blake, told us 200 years ago: "One law for the lion and ox is oppression." Even worse than one law for the lion and ox is the attempt of Doctor Moreau in H. G. Wells' story to chop both lion and ox by plastic surgery into a tortured semblance of human beings. Sometimes, when I am visiting graduate schools of physics and listening to the heart-rending complaints of the students, I am unhappily reminded of Doctor Moreau's Island.

Please forgive me for talking frankly. I am perhaps exaggerating the miseries of our graduate students. But I do not think I am exaggerating the harm that the Ph.D. system is doing to the pursuit of science in this country. Drastic changes are bound to come. If you do not like my proposals, please go home and think of something better.[5]

IV. BACK TO SCHOOL

That is all I have to say about higher education. I now return to elementary education, which most of the experts agree is at the root of our difficulties. I have said that our children need both Nappi's suggested remedies and mine. So then, you may ask, what am I asking the educational establishment to do? Am I suggesting that we give to each child, or to each teacher, or to each school, or to each district, the choice of learning in a structured Italian-style environment or of running wild and free? Is it possible in the real world of 1991 to offer such a choice? My answer to these questions again goes back to the experiences of my childhood.

I learned very little science, except for mathematics, in school, but I learned a lot of science in other ways. I learned mostly from two sources, books and museums. The enormous advantage of books and museums is that a child comes to them freely, not under compulsion. Even if a child is forced to visit a museum as a member of a supervised group, there is a lot of running around and it is not as bad as sitting in class. Most of the children one sees, either in public libraries or in museums, seem to be enjoying themselves. So my first recommendation to people in charge of science education is, more money for public libraries and museums. Public libraries and museums ought to be as common as schools. Then we could have, side by side with Nappi's regular classroom instruction, an alternative for children who learn better on their feet than on their behinds. I was delighted to learn yesterday at the meetings, from Marjorie Bardeen, about the program to bring Junior High School kids to talk with scientists at Fermilab, and from Jorge Flores Valdez about the new science museums that are growing up in Mexico City.

Besides libraries and museums, children also need to be exposed to laboratories and computers. Here, again, the essential problem is to make sure that the exposure results in attraction rather than repulsion. Being forced to chop up a frog in a laboratory is worse than being forced to learn the periodic table of elements in a classroom. Children who enjoy chopping up frogs had better do it in their own time, with their own frogs. Children who enjoy optics or electronics should be given the materials to build microscopes or radios. If materials are available and children are given

enough free time, they will learn more from one another than they learn from teachers. Children who enjoy computers should be let loose, to play with as large a variety of hardware and software as we can afford to give them. Computers should be a part of the landscape which children are free to explore, not a required course that they have to take for credit.

The generation that is now young has three good reasons for turning away from science. Science is presented to our young people as a rigid and authoritarian discipline, tied to mercenary and utilitarian ends, and tainted by its association with weapons of mass murder. These three reasons for hating science are real and serious. It is useless to pretend to our children that these three ugly faces of science do not exist. Children will not be fooled. If we try to fool them, they will turn away from science even more. Our task as educators is to show our children that science is a hexagonal mountain with six faces, with three beautiful faces in addition to the three ugly faces. The three beautiful faces of science are, science as subversion of authority, science as an art form, and science as an international club. The way to attract young people into science is to show them all six faces and give them freedom to explore the beautiful and the ugly as they please.

Science as subversion has a long history. There is a long list of scientists who sat in jail and other scientists who helped get them out and incidentally saved their lives. If science ceases to be a rebellion against authority, then it does not deserve the talents of our brightest kids. I was lucky to be introduced to science as a rebellion against Latin and football. We should try to introduce all our children to science as a rebellion against poverty and ugliness and militarism and economic injustice.

Another face of science that children should explore is science as art. We heard this morning from John Coletta about the meeting at Amherst in 1923 of Niels Bohr and Robert Frost. This was not a mere social encounter but a genuine meeting of minds. One can find many traces of Bohr's ideas, and even of quantum mechanics, in Frost's poetry. Another writer who knows how to turn science into art is Jeremy Bernstein, whom we are honoring this afternoon with the Gemant Award. The immense popularity of Maurits Escher shows how fruitful an educational tool the marriage of science and art might be.

Finally, the sixth face of science is the most beautiful of all, science as an international club. We saw something of this international club in action yesterday, at the session on International Education chaired by Yvette Van Hise. Instead of being tied to weaponry and narrow patriotism, science is and always has been an international enterprise. If you are a scientist, you have friends in every corner of the globe. Scientists in every country are linked by personal contacts with the world outside. Scientists in good and bad situations are fighting as best they can for open communications and international collaboration. Little by little, one step at a time, the international commonwealth of science is growing in strength. Slowly, that great dream with which Niels Bohr tried in vain to inspire Franklin Roosevelt and Winston Churchill, the dream that the international commonwealth of science might be a model for a peaceful international commonwealth of nations, is coming closer to reality. In the international eradication of small pox, in the Montreal convention for the preservation of the ozone layer, and in the burgeoning of environmental movements all over the world, we see examples of Bohr's dream coming true. When international science takes the lead, the politicians and the diplomats cautiously follow. To be a scientist means to take a hand in pushing Bohr's dream along toward its final goals, the open world, the abolition of weapons of mass murder, the obsolescence of war. What the kids in the ghetto need, to open their minds to science, is not more hours of physics and chemistry, but a vision of a future that will be different from the past. A dream of a better future; that is what our kids need. And that is what science, if we don't confuse science with SAT scores, can give them.

[1] *Proceedings of the Gibbs Symposium, Yale University, 15–17 May 1989,* edited by D. G. Caldi and G. D. Mostow (American Mathematical Society, Providence, RI, 1990), pp. 269–276.
[2] C. R. Nappi, "On Mathematics and science education in the U.S. and Europe," Phys. Today **43**(5), 77–79 (1990).
[3] N. Bohr, "Discussion with Einstein on epistemological problems in atomic physics," in *Albert Einstein, Philosopher-Scientist,* edited by P. A. Schilpp (Library of Living Philosophers, Evanston, IL, 1949), Vol. 7, p. 240.
[4] S. Coyle, *The Long Haul to a Doctorate* (National Research Council, Washington, D.C., 1990), preprint.
[5] For further reading on science education at the college level, I recommend Sheila Tobias, *They're Not Dumb, They're Different* (Research Corporation, Tucson, AZ, 1990). I am grateful to Tobias for a copy of her book.