THE PROBLEM OF TEACHING PHYSICS IN LATIN AMERICA

by Richard P. Feynman

The problem of teaching physics in Latin America is only part of the wider problem of teaching physics anywhere. In fact, it is part of the problem of teaching anything anywhere – a problem for which there is no known satisfactory solution.

There are many new plans in many countries for trying to teach physics, which shows that nobody is satisfied with any method. It is likely that many of the new plans look good, for nobody has tried them long enough to find out what is the matter with them; whereas all the old methods have been with us long enough to show their faults clearly.

The fact is that nobody knows very well how to tell anybody else how to teach. So when we try to figure out how to teach physics we must be somewhat modest, because nobody really knows how. It is at the same time a serious problem and an opportunity for new discoveries.

The problem of teaching physics in Latin America can also be generalized in another way, to remind us of the problem of doing *anything* in Latin America. We must get at least partly involved in the special social, political, and economic problems that exist here.

All the problems come into sharper focus if there is before us a clear picture of the reasons for teaching physics in the first place. So I will try to give some reasons why I believe we should teach physics. We can then ask whether any particular educational plan is in fact satisfying any of the reasons.

The first reason is, of course, that physics is a basic science, and as such is used in engineering, chemistry, and biology, and has all kinds of applications in technology. Physics is the science, or knowledge of nature, that tells us how things work. In particular, I am stressing here how devices of various kinds—invented by men in present and forthcoming technology – work. Therefore, those who know physics will be much more useful in coping with the technical problems arising in local industry.

It might be argued, and in practice it is argued, that in the earlier stages of industrial development that we have in Latin America, such talent is completely superfluous because it is so easy to import good technically-trained personnel from more advanced countries outside. Therefore, is it really necessary to develop highly-technically-trained people locally?

I probably do not know enough economics to answer correctly, but I will try to give an opinion anyway. I think it is vitally important to improve the technical ability of the peoples of Latin America. By education, the man with higher technical ability is able to produce more, and I believe that in the improvement of the technical ability, and thus the productivity, of the people of Latin America lies the source of real economic advancement.

It is not economically sound to continuously import technically-skilled people. If Latin American people were educated technically they would find positions in the developing industries here; it would soon be realized by the people who now import such workers that there is a supply of really able men in this country, and that this local supply has many advantages. The local people would not demand such high wages, would know the customs and ways of the country, and would be glad to take more permanent positions.

It is true that Latin Americans with the same degrees in science or engineering as their foreign counterparts seem to be very much less able. This (as I shall explain) is because they have not really been taught any science. This experience has probably conditioned industrialists to pay very little attention to the local universities and scientists. If they were wise the industrialists would see the problem quite the other way around and would be the first to clamor for a meeting of the kind we are

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having today, to find out what is the matter with the local product and how to teach physics in a really satisfactory manner in their countries. Yet none of them are here.

A secondary reason for teaching physics, or any experimental science, is that it incidentally teaches how to do things with your hands. It teaches many techniques for manipulating things — as well as techniques of measurement and calculation, for example — which have very much wider applications than the particular field of study.

Another major reason for teaching physics is for the science itself. Science is an activity of men; to many men it is a great pleasure and it should not be denied to the people of a large part of the world simply because of a fault or lack in the educational system. In other words, one of the reasons for teaching science is to make scientists who will not just contribute to the development of industry but also contribute to the development of knowledge, joining others in this great adventure of our times, and, of course, obtaining enormous *pleasure in doing so.*

Thirdly, there is good reason to study nature to appreciate its wonder and its beauty, even though one may not become an actively-working professional scientist. This knowledge of nature also gives a feeling of stability and reality about the world and drives out many fears and superstitions.

A fourth value in teaching science is to teach how things are found out. The value of questioning, the value of free ideas — not only for the development of science, but the value of free ideas in every field — becomes apparent. Science is a way to teach how something gets to be known, what is not known, to what extent things *are* known (for nothing is known absolutely), how to handle doubt and uncertainty, what the rules of evidence are, how to think about things so that judgments can be made, how to distinguish truth from fraud, and from show. These are certainly important secondary yields of teaching science, and physics in particular.

Finally, in learning science you learn to handle trial and error, to develop a spirit of invention and of free inquiry which is of tremendous value far beyond science. One learns to ask oneself: "Is there a better way to do it?" (And the answer to this is *not* the conditioned reflex: "Let's see how they do it in the United States," because there must certainly be a better way than that!) We must try to think of some new gimmick or idea, to find some improvement in the technique. This question is the source of a great deal of free independent thought, of invention, and of human progress of all kinds.

This ends my list of reasons for the teaching of physics as a science. Let me turn now to a description of some of the major characteristics of science education in Latin America which appear to me to be of special concern for us.

First, and most serious, I believe, is the almost exclusive teaching and learning by means of pure abject memory. This in no way teaches physics as a science. Nothing is understood; it is only remembered. This in no way satisfies the reasons I outlined for teaching science. Memorization of laws does not permit one to make applications of these laws to new situations; it does not permit one the pleasure of ultimately making scientific contributions; it cannot teach any techniques with the hands. From memorizing, knowledge is not understood, and the beauty of nature is not appreciated. It does not tell how things were found out, or reveal the value of an inventive free mind.

For example, the telescope is an interesting device to make, understand, look through, and play with. It turned men's ideas and minds in new directions. It gave a great impetus to the modern revolution of thought. For a long while it was the sole revealer of the vastness of the heavens and man's modest place in it. But, in Latin America one learns that there are four kinds of telescopes: the Newtonian, the Cassigranian, etc., etc. In the first, the image is virtual and inverted, etc. (I put in all this "etc." because I really don't know how many kinds of telescopes there are, or what their names are, or which way the image is in each kind. But don't underestimate me; I know a very great deal about telescopes — how they work, how to make and use one, their powers and limitations, etc.) The result is that the telescope is lost. There is no more telescope, no lenses, no stars, no eyes, no light — just words memorized without requiring understanding. The examination is passed, for the question was "What are the four types of telescopes?"

I must say immediately that I am not against memorizing. Some things, even many (though nothing special) may be learned by heart; for example, it is good, but not essential, to know by heart $7 \times 8 = 56$. What I oppose in any teaching philosophy is that the philosophy is used exclu-

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sively; but in this case it is especially serious because so little is left of the subject.

It was incomprehensible to the people of my country when I reported how material is memorized in Latin America completely without understanding. Lectures are dictated so slowly that students can copy them word for word into their notebooks – and sentences are even repeated so they can check them back.

When asked what Brewster's Law is, advanced students answer in a flash: "Light impinging on a material of index n is 100 percent polarized with the electric field perpendicular to the plane of incidence if the tangent of the angle of incidence equals the index of refraction."

To these same students I then say, "Look out at the bay from which the sunlight is being reflected. If I look at that reflection through this piece of polaroid and turn it, what will happen?" All I receive are blank stares. No one knows. But I get cries of surprise and delight when they try it and see the reflections getting brighter and dimmer.

This shows something is completely wrong. There is no knowledge whatsoever of nature. With the wrong entrance clue the memorization is useless. These students are like books, no more. I can look in the index of a book under "Brewster's Law" and find a reference equivalent to the students' reply. But in the index I cannot find "sun reflecting on bay."

What do the students know that is not easily and directly available in a book? The things that can be looked up in a book are only a part of knowledge. Who wants such a student to work in a plant when a book requiring no food or maintenance stands day after day always ready to give just as adequate answers? Who wants to *be* such a student, to have worked so hard, to have missed so much of interest and pleasure, and to be outdone by an inanimate printed list of "laws"?

What experience I have makes me think that this is one of the main failures in the education of students in Latin America.

A second problem in Latin America is that the students are all alone. They cannot converse with other students; they cannot see how stupid some fellow students are. This is mainly for some psychological reason. They do not wish to be found unsure, for they will be ridiculed. They cannot ask questions in class because the others later say, "Why do you waste the time of all of us? Everyone knows that." So, to save face, they all put on a show of knowledge, thereby frustrating free discussion and the exchange of ideas—one of the pleasantest and easiest ways of learning things. There is too much show, and too much formality in the classroom for any exercise of free thought and discussion.

A third problem is the lack of freedom in the university structure. You cannot move around from one subject to another or from one lab to another. Those who go abroad to learn find it difficult to communicate their new knowledge easily and directly to the university students when they return—for they cannot find a place in, and are not welcomed into, the university structure. For some reason or other, it becomes necessary for such people to create new and separate research institutes. The spirit of excitement in these institutions as their research progresses is not found in the universities, and this is quite unfortunate.

Another problem in Latin America is that there is very little outlet for the students who do not want to become complete scientists. It is not easy for them to obtain jobs in the developing industries here. Perhaps if these students were really adequately trained, the companies would gradually realize their value and this problem would disappear. But some of the enthusiastic students are not geniuses, and there must be some place for them to go—even though they are not going to make any scientific contribution, or become second Einsteins.

When I began studying at MIT I started in mathematics, and probably I thought I would be a mathematician. Then I discovered that the only use of higher mathematics is to teach more higher mathematics and I turned to something more practical—electrical engineering. Finally I realized I had gone too far in the other direction and chose something in between—physics.

This was all very easy because, for such closely related subjects, the courses taken by students in each discipline were almost exactly the same and were taught by the same professors. The engineers studied physics taught by the physicists, for instance, and the physicists learned some of their electricity in a course taught by the professors of electrical engineering. It is easy for students to move back and forth among related disciplines. If physics is too difficult for them, or mathematics too abstract, they can turn to engineering and can later expect to find a position somewhere. Such

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changes are much more difficult in Latin American universities.

Another characteristic of the situation in Latin America is the small number of people involved: the result is a rapid fluctuation and irregularity in the character of organizations and institutions. How something goes depends very much on particular individuals.

Finally, we must mention the problem of the best students leaving to go to other countries. This is because of the lack of opportunities in Latin America, the climate of rigidity that exists in the universities, and the vagaries of fortune of the research institutions as their budgets find uneven support from year to year, from the government and private sources of funds.

I should now like to give some of the questions for which I think we must seek answers here.

First, how can we free the lower levels of secondary education from the drudge memorization that exists at the present time? It is well known that you can get children quite interested in science in a true, live, and active way while they are young. It is sometimes said you cannot get them interested by the time they are in the university, but this is not true—provided they have not been destroyed as thinking humans at the earlier levels.

Gibbon said: "The power of instruction is of little efficacy, except in those happy dispositions where it is nearly superfluous." This is not really true. It is true of good instruction, but bad instruction can be very efficacious indeed in impressing on one how impossibly dull some subject is. It is possible to destroy the excitement and interest that students may have gained by discovering a small book in the library, by buying a toy, a chemistry set, or a little electric motor—by playing around. In fact, one of the most important sources of motivation of interest in science is in a toy, or in a special book, and from those few teachers who are free enough from the bonds of an educational system to be able to keep children excited and inspired by supplying them with suggestions, demonstrations, and games.

It is a well known experience in education that, in spite of all plans and programs, ultimately almost everything depends on teachers—on individual teachers. You can have poor teachers and, no matter what you try to do with them, the students learn very little. Or you can have good teachers and it doesn't make much difference what you do, *provided* you leave the teacher free. So I think we must find how to free those few teachers who can be inspiring to children. It is important that those inspiring teachers work along with children, suggesting experiments and trying them freely.

The second question we shall have to try to answer is how to bring engineers and other applied scientists closer to their real world of application. It is not enough for them to remember exactly how to use the formula, providing that the situation is exactly the same as the situation was in the engineering school when the professor dictated the lecture. We must do something to make the applied engineer more flexible, so that he is effective in a wide range of applications.

One way may be to have true scientists – and especially active research experimental physicists –teaching physics to some engineering students. Experimental physics generates technical problems. To succeed, you have to work with your hands; you have to meet reality; pure memory won't do. So, people who are good at experimental physics know what engineering problems are.

The development of industrial technology is in a great measure simply the wider application of techniques which in most cases were developed by scientists trying to do experiments. This is because, in trying to do some experiment in science, you have to push some technique to the extreme. In doing so, you learn how things can be done. Experimental physicists first pursued the problems of how to make a higher vacuum or a lower temperature than ever before, and now high vacuum and low temperatures are tools of industrial technology.

Therefore, experimental science is a source of engineering and experimental science should be taught to engineers in school to keep them aware of the wide range of techniques available and the open possibilities of the future. Perhaps, then, after we have created enough real engineers with real value to industry in Latin America, industry will see that there is no advantage to hiring engineers from overseas and will want more of the locally-trained men and will support the schools with methods of teaching which produce such engineers. Then we will have the ball rolling.

I understand that the number of engineering schools in Latin America is growing rapidly. For example, in Brazil there are twice as many en-

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gineering schools as there were ten years ago. If this is the case, then maybe the problem can solve itself. If these schools are not all organized under the same system, if there is a variety in the schools, then one or another school may develop a way to produce excellent students—if the secondary school preparation has not first ruined them. Then this school will acquire a reputation, children will try to go there, other schools will try to compete and copy the better methods—and so on until the problem solves itself.

The third problem that we have here is how to encourage the true research workers and keep them from leaving home permanently. We have to supply them with books, with experimental equipment, with money for visits abroad, and with a coterie of active interested students. No, excuse me—the coterie will form automatically if the researcher is good and can get to students in any way at all.

It is imperative to encourage the true research worker who is making contributions to science to make his home base in his own country. This should not be hard because there are strong feelings of patriotism in these men; they know they have a great deal to give their country and *want* to give it. The difficulty is the terrible problems they have at home. For example, the physics research center in Rio, which is one of the leading ones in Latin America, has become isolated from the rest of the world because of a very simple thing: Nobody wants to pay for the *Physical Review* or *Nuovo Cimento.* Nobody wants to pay for the journals that can keep people informed of what happens somewhere else.

This, along with the fact that salaries are absurdly low, shows a lack of interest by the Brazilian government, people, and industry, in the development of science in this country. It is an attitude that does not respect or understand the value of these men. These creating scientists should have a dignity and a power to control their own destiny, and that of science and of science education in their countries. It will be in safe, loving hands.

It is from the fountain of research workers who understand what science is really about that the true spirit of inquiry rains onto their students, and their students' students, and ultimately, if things are organized right, permeates the entire educational system and speeds the technical development of the country.

The fourth problem, then, is how to get these research workers back into the universities where they belong. Then the "rain" will have a far easier and direct passage to the students, the new scientists of the country.

I should like to emphasize, by addressing my fifth and final question to the problem, the importance of doing any of these things in a steady, consistent, continuous, and modest way. It should not be done with a big show, the big money, with much advertising, unsupported in the future by any effective maintenance. Maintenance is lacking in many of these projects, for these things have happened before. Pulses of energy have been liberated, forward steps have been taken, only to slip back for lack of continued support. It is necessary to keep up anything that works out. It is necessary to provide a continuous, consistent, perpetual support and to make things more modest so that continuity of support can be maintained. A research group becomes world famous only after years of fruitful research. One year of no support and people drift away and there is nothing left.

I appreciate that this is a problem of great difficulty and seriousness because it involves so closely all of the social and economic circumstances in the country, and the difficulties are often (but not always) merely the reflection of the vastly more serious problems of the varying fortune of the country as a whole. Yet we ought to discuss it further here. We might try to see if there are ways to work out a scheme so that the educational system, or at least such critical parts of it as research scientists or especially good teachers, is partially independent of the variations in success of the government.

Perhaps it should not be completely supported by government. Perhaps greater efforts to obtain private funds might work. Possibly more reliance on, and contact with, more permanent institutions like religious schools might sustain the continuity of these efforts.

I have discussed the problems as directly and frankly as possible, as I see them. I don't mean to make any criticism, except in the same spirit as any discussion we shall have later will represent a criticism. For surely we shall not all find everything well with the present situation in physics education in Latin America. If so, we would not have had such a meeting. I have tried to avoid making too many specific active suggestions on how to proceed, because this is our job for the rest of this meeting.