

Setting new directions in physics teaching: PSSC 30 years later

The famous high-school physics course sought to excite students and prepare them for life in a technological society; three decades after its inception, it has also taught us important lessons about educational innovation.

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In 1945 the United States emerged from World War II—into a world profoundly altered by scientific growth. Under the pressure of wartime conditions, sophisticated technology—most notably radar—had been developed by exploiting basic physical principles, such as those of electronics and atomic phenomena, and this technology had proved crucial to the war's outcome. Yet in the postwar US, fewer than 25% of high-school students were studying physics at all, and what physics was taught emphasized rote learning and superficial description. Similar situations existed in the teaching of mathematics and of other sciences.

Jerrold R. Zacharias, a professor of physics at MIT, developed the strong conviction that existing physics courses were inadequate to equip young people for life in a society in which science and technology played an ever increasing role. In 1956 he took the first steps to bring about a fundamental change in American high-school education. His approach, perhaps without precedent in the educational field, was to mount a massive and coordinated team effort of

the kind that had been so successful in major scientific projects—such as the development of radar—during World War II.

Getting started

Zacharias formed a group—the Physical Science Study Committee—made up of a combination of university physicists, educational specialists and high-school physics teachers from across the nation. Among them were some of the most distinguished physicists of our time—such as Philip Morrison, Edward Purcell and Hans Bethe. In November 1956, with an initial grant of \$300 000 from the National Science Foundation, Zacharias began a program to create a complete physics course from scratch.

PSSC held¹ its first major planning meeting on 10–12 December 1956. Stephen White, one of the participants, later described² in detail the policy decisions taken at that meeting. Perhaps the most important were the choices to design the PSSC course for such students as were already choosing to study physics (primarily the academically superior, college-bound students) and to make it a one-year course, despite the belief that two years would have been justified and desirable. These decisions, as White pointed out, were ones of expediency, growing out of a recognition that if PSSC tried to

break the constraints of existing educational practices, it would simply lower the course's chances of gaining use and acceptance.

In addition to these strategic decisions, the committee developed some principles concerning the structure and content of the course. Existing courses were, to quote White, a "patchwork" of Newtonian mechanics and other areas of classical physics, with a smattering of more modern physics and an emphasis on applications rather than on fundamentals. The PSSC course would seek to present physics as an integrated intellectual activity, not as a set of mechanical rules for solving problems and manipulating nature. The course would be designed to reflect a spirit of inquiry, presenting both theory and experiment as processes of successive approximation, not as definite or final knowledge. The most basic and universal features of the physicist's description of nature—such matters as orders of magnitude and the effects of changes of scale—would be stressed. There would be a unifying theme—the atomic, particulate picture of the universe—in the presentation and discussion of the subject matter. Also, in the interests of achieving depth of treatment, substantial areas of traditional material (such as sound) would be omitted. The goal was to get stu-

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Working on PSSC in 1957 are, from left to right, Fred L. Ferris Jr of the Educational Testing Service, one of the leaders of the PSSC test-development group; Jerrold R. Zacharias of MIT, the driving force behind PSSC; and Francis L. Friedman, also of MIT, the principal author of the PSSC text.

dents to think and act like professional scientists: to learn to ask questions, collect and analyze data and form reasoned conclusions.

There were also what White called "antiprinciples"—what the course would *not* expect to do. The committee members did not start out with the specific intent of creating more scientists and engineers (although they no doubt hoped that the intrinsic excitement and challenge of the course might attract more students generally into high-school physics). Second, there was no intention to depreciate or diminish the role of the teacher. And there was to be no "final" course structure or textbook: Both would be subject to continuing review and revision.

Creating the course

Although a major task in creating the PSSC course was to define a syllabus and produce a textbook, the committee from the outset considered the role of the laboratory as central. And the laboratories were undoubtedly a high point of the program. Students were drawn into direct explorations of

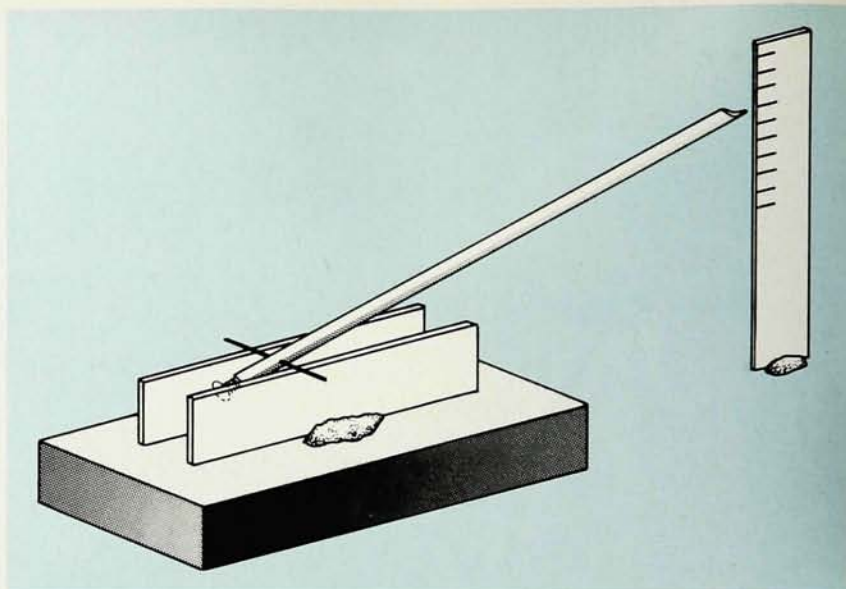
space, time and matter, learning first-hand how to extend their senses with the help of simple and ingenious devices. It is hard to imagine anyone not being thrilled and impressed on introduction to the soda-straw balance—so simple, yet capable of responding to the weight of a single hair. The ripple tanks the course used to display wave phenomena did their job so vividly and effectively that they have become a commonplace in high-school physics. And these were only two of many novel resources.

The rest of the project was equally characterized by originality and freshness of approach. The first edition of the textbook, published in 1960 with Francis L. Friedman as its principal author, had a quite unorthodox ordering of topics—which, regrettably, has been partly abandoned in more recent editions. It was stimulating, in place of the usual introduction via the mathematics of motion, to be confronted immediately with basic questions of measurement and scaling that could be directly tested in the laboratory. The particulate structure of matter made

an early appearance. Both geometrical and wave optics came before any immersion in Newtonian dynamics—another pedagogically imaginative feature.

A central component of the program was a set of about 50 instructional films keyed closely to the textbook. The films presented phenomena or situations too complex, subtle or difficult to be studied in the high-school laboratory—such things as the Millikan oil-drop experiment or the counting of individual photons. As show business, the films perhaps fall short. Gilbert Finlay has said³ that "the films do not glitter. There is no background music." And most physicists do not have great stage presences (though exceptions must be made for Eric Rogers, with his film on Coulomb's law, and for Patterson Hume and Donald Ivey, whose *Frames of Reference* is probably the most enduring and popular film in the whole series—the *Casablanca* of physics!). But as Finlay also remarked, the films are honest: They represent real experiments using real data. One of the most impressive in this regard is

Soda-straw balance. In this simple instrument used in the PSSC course, a drinking straw, pierced near one end with a needle, pivots on the edges of two microscope slides fixed with modeling clay to a baseboard. A machine screw inserted in the lower end of the straw acts as a counterpoise and provides a quite delicate control of the equilibrium orientation of the straw. An object such as a human hair, placed at the far end of the straw, produces a measurable deflection of the tip, yielding quantitative measures of very small masses.



Forces, by Zacharias himself. His demonstration of the gravitational attraction between boxes of sand and bottles of water—one frame from which is shown on page 33—was a *tour de force*; students and teachers anywhere could now see with their own eyes an extraordinarily subtle phenomenon.

At every stage PSSC tested out the new materials in schools; the feedback so obtained was an important part of the project. Walter Michels and Frederick L. Ferris led the extensive effort that went into devising a batch of new tests and examinations for use with the course. Finally, the course provided a wealth of supplementary reading through the *Science Study Series*, more than 40 original monographs about topics of special interest (including the lives of notable scientists, such as Johannes Kepler, Count Rumford and J. J. Thomson, and famous episodes in physics as in George Gamow's *Thirty Years That Shook Physics*, the story of the development of quantum theory).

From the outset PSSC recognized that a crucial part of the whole enterprise was equipping the average teacher to handle this novel and challenging material. A vast amount of work went into preparing a detailed teacher's guide, far more bulky than the textbook itself. Beyond this, an ambitious program of teacher-training institutes brought many hundreds of teachers into direct contact with those who had helped to create the course.

Growth at home and abroad

Zacharias liked to emphasize that the PSSC program was well under way almost a year before the Russians launched the first Sputnik in October 1957. Nevertheless, the jolt that this Soviet achievement gave to US compla-

cency was undoubtedly a powerful stimulus to the flow of both government and private funds into PSSC and similar projects in other scientific fields. The PSSC budget itself rose quickly to about \$1 million per year and remained at that level for about five years in the late 1950s and early 1960s. It is impossible to overestimate the importance of the support provided by the National Science Foundation in making the whole project possible.

Use of the PSSC course grew rapidly over its first few years. The preface to the first edition of the textbook records that the course, as it was being developed, was used by 8 schools and 300 students in 1957–58, by 300 schools and 12 500 students in 1958–59 and by nearly 600 schools and about 25 000 students in 1959–60. These numbers are all relatively small, of course, when measured against the background of about 15 000 teachers teaching physics to about 500 000 students during those years. However, by the time the course had achieved its full impact, around the late 1960s, it was reaching well over 100 000 students each year.

The above figures refer only, of course, to the US, but one of the remarkable things about the course was the use and influence that it achieved abroad. The textbook was translated into 17 different languages. This is particularly striking in view of the fact that most countries with well-developed systems of secondary education spread their physics courses over several years of high school, giving a much more intensive and detailed exposure to the subject than can be attempted in the typical one-year course in the US. But the PSSC course may have exerted a special appeal by virtue of the high intellectual quality of its presentation. Nahum Joel (former-

ly with the Science Education Division of UNESCO) has told me that there was even a Russian edition of the PSSC textbook, running to 57 000 copies—enough for every physics teacher in the Soviet Union!

There can be no doubt that the PSSC course had a major impact on the way physics is taught in secondary schools—and not only in the US, as I have just mentioned. Even within the US, its influence is not to be measured merely by the sales of the textbook or by the numbers of schools and students using the course. One has only to look at recent editions of other widely used high-school physics texts to see how they have picked up and incorporated portions of the PSSC approach. There is good reason for this: The PSSC program was the first organized attempt to present physics as a living endeavor, seen through the eyes of professional physicists.

However, as Zacharias himself acknowledged, PSSC certainly did not solve all the problems. For one thing, it did not lead to the hoped-for increase in the number of high-school students electing to take physics. It can be (and has been) argued that the course, although exciting to the scientifically inclined student, was too difficult, and perhaps just not suitable, for the rest. The Harvard Project Physics course, developed a few years later, was designed with a view to addressing this problem; it was well received, but did not significantly alter the picture. Indeed, the declining enrollment figures for physics in the high schools—from about 25% of those who graduated high school in 1955 to about 15% today—have become⁴ distressingly familiar. The actual percentage of high-school physics programs in which the PSSC course is used appears also to have



Frames of Reference. Patterson Hume (left) and Donald Ivey in the opening sequence from the classic movie. Hume has just pointed out that Ivey is upside-down.

declined substantially, by a factor of about two—perhaps even more.

Some lessons

Probably the most important single lesson to be learned from the PSSC project is that it is very hard to sustain an educational innovation, however meritorious. Pressure from the educational system not only has decreased the number of schools using PSSC physics but has also forced its textbook back into a more traditional mold. Courses such as PSSC and Harvard Project Physics, which emphasize open inquiry and the provisional character of scientific knowledge, place greater demands on teachers than does a more traditional course, and this too has taken its toll. As George Pallrand and Peter Lindenfeld put it,⁴ the typical high-school teacher is not “a surrogate

scientist.”

Unhappily, it also appears that it is extremely difficult to achieve and maintain any attempt to convey the richness of physics with a wide variety of teaching aids—films, laboratories, supplementary reading and so forth. Some of the difficulties are organizational and logistic—for example, the individual teacher’s problem of arranging to obtain rented films at the appropriate point in the course. Others arise from simple obsolescence, a phenomenon to which the PSSC films, featuring real people, are particularly vulnerable. Young students are notoriously intolerant of “funny” haircuts and other evidences of an earlier culture. The role of long films in themselves is a matter for debate; many people think that short, depersonalized demonstrations—such as the film loops of ripple-

tank experiments prepared for PSSC—are, in general, a more effective use of this medium. (It will be interesting to see how the new “Mechanical Universe” television program fares in this respect.) But what one comes back to again and again—and not only in connection with physics courses at the high-school level—is the dominance of the textbook. The reasons are familiar: It is relatively cheap, it defines a ready-made path for the instructor and it entails no expensive investment for classroom space or equipment. The attempt of PSSC to focus equally strong interest in the laboratory has been seriously eroded, and the *Science Study Series* has long been out of print.

Finally, and not surprisingly, the years have made clear that the crucial ingredient for the success of any educational innovation is the classroom



Demonstrating gravitational attraction. In this photo from the PSSC film *Forces*, Zacharias shows how two boxes of sand deflect bottles of water mounted on a meter stick suspended from an extremely long ribbon of magnetic recording tape. The markings on the wall indicate the undeflected position of a reflected spot of light and its position after the boxes of sand were put in place. The meter stick and bottles can be seen dimly inside the case that shields them from drafts and electrostatic disturbances.



PSSC workshop. Three teachers are using a ripple tank in this photo from a teacher-training institute held in 1957. Such workshops were an integral part of the PSSC program, bringing many hundreds of teachers into contact with those who were developing the course.

teacher. The history of PSSC shows that large numbers of teachers responded enthusiastically to the revelation of what a physics course *could* be like; many of them, 30 years later, attest that it changed their professional lives. But it has been hard to maintain a supply of high-school teachers with the competence and the confidence to handle such a demanding course. Many teachers, through no fault of their own, simply lack the professional background to do this, and bringing and keeping high-school physics teachers up to date continues⁵ to be a matter of major concern. This problem is aggravated by the almost complete lack of young physics teachers entering the profession.

Prescriptions for future reforms

It was 25 years ago, at the 1961 joint winter meeting of APS and AAPT, that Zacharias was awarded AAPT's Oersted Medal for his achievement in creating PSSC. (The medal was presented by Francis W. Sears, whose publishers had just announced the sale of the millionth copy of his collective textbooks!) In his address at that meeting, "Team approach to education," Zacharias spoke⁶ of his hopes that the course would serve as "part of a greater effort to make science part of our culture, and to make learning a part of everyone's life." His theme was that this was largely a numbers game involving people, time and dollars, and that a real and lasting improvement in our educational system would require substantial and continuing investment in all three categories.

But perhaps without fully realizing it, the makers of PSSC physics were speaking mainly to their own kind. The problem of reaching the average student remains unsolved, and even among the academically talented, scientific literacy is the exception. Physics teaching in the high schools has (or should have) a broader aim than to prepare future scientists for their university careers. Probably nothing significant can be done about that until we find more effective methods for awakening scientific interest in students at an early age and keeping them interested instead of alienating them.

Without in any way contradicting his 1961 prescription, Zacharias himself more recently stressed the importance of making effective contact with students at both the high-school and pre-high-school levels, by finding what really appeals to them. In a conversation with me last January, he even speculated that "physics based on the automobile engine and taillight" might offer an effective strategy for teaching younger or less academically oriented students—an interesting departure from the philosophy that inspired PSSC. Perhaps something along those lines will reach the 80% of high-school students who have not been taking physics at all, and whom the PSSC program did not really expect to reach.

The PSSC course was a landmark, not just in physics education but in education generally, and the way it was organized and conducted has provided a worthy model for many subsequent curricula and other educational projects. Still, although devising exciting

new curricula is valuable, it is in itself no answer to the deeper problems of science education. It may even be a mistake to try to move a teacher from a program that he or she does well into a novel program with which the teacher feels uncomfortable or inadequate.

This is not meant to be an argument against innovation, and Arnold Arons, in an excellent early description of the PSSC course, vigorously repudiated⁷ the above objection. Thirty years after PSSC's start, the time is ripe (or over-ripe) for another injection of fresh ideas and fresh people into the field of high-school physics. One encouraging sign—not limited to PSSC—is AAPT's new Physics Teaching Resource Agents program (funded by the revived Science Education Directorate of NSF), in which specially selected teachers serve⁸ as instructors and models for much larger numbers of other physics teachers across the nation—a reincarnation of the "each one teach one" strategy that worked so well, under Finlay's general guidance, in the early days of PSSC. The initial results have been impressive—several thousand teachers have already been reached through this program. Coupled with the revived awareness of the crucial importance of science education to our national welfare, this may presage a new era in physics education in the high schools. One must certainly hope so.

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This article is based on an invited talk at the APS-AAPT joint winter meeting held in Atlanta in January 1986. Just as I was about to submit the article, the news came that on 16 July 1986 Jerrold Zacharias had died. Although I did not conceive it as a memorial tribute to him, I hope the article will be read in that light. His contributions to education—and not to high-school physics alone—were numerous and immeasurable.

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