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about the current use of the PSSC experiments. Haber-Schaim tells me that the sales of the laboratory guide are running about on a par with those of the textbook. Since I believe that the PSSC course, with its various components, is still the best high school course in existence in this country, I am happy to be corrected in this regard. Also, since in my article I lavished praise on the laboratory part of PSSC, I should like to take this opportunity to recognize Haber-Schaim's prominent role in its development.

Reference

1. U. Haber-Schaim, Phys. Teach. **6**, 66 (1968).

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Research in the colleges

In "Physics in the colleges" (June, page 28), Jerry Gollub and Neal Abraham assert that "research [in undergraduate institutions] enhances the education of their students and the professional life of théir faculty," and they recommend that colleges take steps to increase the reseach output of their physics departments. Yet some of their own observations highlight the inevitable conflict between education and research. They say, "Probably the single greatest challenge that college departments face is providing an adequate diversity of upper-level offerings while reserving sufficient time for meaningful research." And later: "A second major challenge . . . is the development . . . of first-rate programs of laboratory instruction," because "typically no individual has time to devote a major fraction of his or her effort to such work." But if college faculty spend more time writing grant proposals and papers, won't they have less time to develop upper-level courses and instructional laboratories? The authors recognize that "science graduates with liberal arts backgrounds . . . have traditionally been valued for the breadth of their intellectual training," but they also argue that undergraduates who participate in research may gain "several years in practical scientific maturity over their counterparts who lack research experience." Here again, we see a basic conflict. A student who spends many hours in narrowly focused research has not spent those hours gaining intellectual breadth. For some students, the tradeoff is worthwhile. For others, perhaps it is not.

Gollub and Abraham display bar graphs that indicate that the "research support raised by college faculty members from external sources" and the "productivity of colleges in training future physicists" (that is, turning out future PhDs) both vary widely among institutions. But is there any connection between these quantities? Using the same source of data,[1] I found no correlation between PhD productivity and either external funding or number of publications, on a per-faculty basis. Perhaps better data would show such a correlation, but if so, let us see them. It seems to me that the burden of proof rests with those who promote increased research in undergraduate institutions and regard PhD productivity as a significant indicator of educational performance. Can they link those two phenomena with anything more substantial than anecdotal data and rationalizations?

Suppose they can. (Even I would expect some correlation.) Let us grant, provisionally, that research in the colleges contributes significantly to their development of future PhDs. Don't physics faculty have other important responsibilities? What about teaching physics to majors in the other sciences? What about providing non-science majors with some understanding of physical science, its technological applications and their impact on society? To me, the real challenge for college physics departments lies in making their curricula more broadly accessible and relevant. Why isn't physics a more attractive pre-medical degree? What about physics pre-law? Or pre-business? Developing research-oriented protégés of research-oriented faculty is not the only educational activity that is (or could be) pursued by undergraduate institutions. What, therefore, would be the broader impact of an increased emphasis on research?

Gollub and Abraham claim that "institutional pressure on faculty members to do research recognizes that their vitality and their ability to remain abreast of current knowledge are at stake." But are grants and publications the only measures of intellectual vitality? Is being at the frontier of a narrow research specialty quite the same thing as being "abreast of current knowledge"? Is it not possible that the effort of a faculty member to maintain currency across a broad range of knowledge may be impeded by pressure to produce new results in one area? Gollub and Abraham warn that "many of the best young physicists would not choose this environment [college] if opportunities for serious research were unavailable." By "best young physicists" they mean, of course, "best young researchers." But do the best researchers necessarily make the best college faculty? Even assuming that they are the best teachers and role models for future PhDs, what about the other physics majors? The non-physics majors? The non-science majors? Even assuming that the best researchers are the best communicators of physics to all audiences, is that the most effective use of their talents? Or is society more effectively served if the best researchers concentrate more on their research? Will increased emphasis on research result in a net gain for physics education, due to an influx of research-oriented faculty into the colleges? Or will there be a net loss, as the present faculty divert time away from course preparation? Where will the money come from to finance increased research opportunities? In other words, what are the tradeoffs here?

Personally, I agree with Gollub and Abraham that research can and does play a useful role in undergraduate institutions, but I think it is already somewhat overemphasized.

Reference

1. Brian Andreen, ed., *Research in Physics and Astronomy at Private Undergraduate Institutions*, Council on Undergraduate Research and the Research Corporation, Tucson, Ariz. (March 1986).

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GOLLUB AND ABRAHAM REPLY: Allan Walstad has articulately emphasized the fact that research activities inevitably compete with instructional activities for the limited time and attention of college faculty. In our article we qualified our emphasis on the benefits of research by a brief discussion of some of these conflicts and a plea that colleges that wish to encourage research provide the time and resources to make this possible. One should certainly not expect everyone to choose traditional research programs. Colleges are in a position to encourage interdisciplinary ventures and imaginative enterprises that might be too risky in universities. There is no reason to measure success primarily by numbers of publications or to pressure faculty who are not much interested in research to undertake meaningless activities.

For those who are interested in doing research, the problem of funding is serious but not usually prohibitive. NSF funding for college research has increased substantially and the Research Corporation is also planning a

major increase. If faculty take advantage of collaborative efforts, modest college research need not be expensive. We agree that there are tradeoffs, but money is less a problem than time for most of us.

We certainly agree with Walstad on the importance of providing high-quality educational experiences for students not intending to major in physics. However, the topic of the June issue of PHYSICS TODAY was the education of professional *physicists*, and that is the reason for our emphasis. Our experience has been that many physicists and administrators are skeptical about the possibilities for doing successful research in colleges. This deters physicists who enjoy both research and teaching (and can pursue both with distinction) from applying for faculty positions in colleges. By providing concrete evidence for the existence of successful college research programs, we hoped to modify this prejudice.

Walstad implies that our case is substantially based on the existence of a correlation between the PhD productivity of colleges and their success in research as measured either by publications or by grant-getting. We made no such claim (though we think that there may be a correlation) because there does not appear to be valid quantitative evidence on which to base it. (We dispute Walstad's claim that data from our reference 6 may be used to show the absence of a correlation. The number of institutions is small, they were preselected for inclusion, and the data for PhD productivity and research success are for different periods.) Our argument that research activities are useful educational experiences for undergraduates does not depend on whether they choose the PhD path or not. However, we personally know many students who chose graduate study after a successful college research experience.

We would like to correct two errors in our article: We regret the omission of an award to Connecticut College from the list of Research Corporation grants. The grant is for studies of photon emission from collisional excitation of N_2O, NO_2 and SF_6. An error also appeared in the profile of Robert Warner of Oberlin College, whose research has received continuous outside support from the NSF since 1965 (not 1985).

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I was pleased that PHYSICS TODAY invited college teachers Jerry Gollub and Neal Abraham to write an article on the important role of college research in both fundamental physics and the education of scientists. Other readers who found the article interesting should be aware of the Council on Undergraduate Research, to which both authors belong, and of whose Physics Council I am president. It is an organization of college faculty who have joined together to encourage research efforts in the undergraduate environment. The directory *Research in Physics and Astronomy at Private Undergraduate Institutions*, referred to in their article, is available from Brian Andreen, Editor, 6840 East Broadway Boulevard, Tucson AZ 85710, for $25 prepaid or $30 charged. It provides useful information about the major private-college physics departments for use by graduate departments, employers, funding agencies, other colleges or high schools.

The CUR also publishes a thrice-yearly newsletter to share ideas about college research efforts, including funding information and case studies. Subscriptions ($22/year) may be ordered from Michael P. Doyle, Newsletter Editor, Council on Undergraduate Research, Department of Chemistry, Trinity University, San Antonio TX 78284.

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Calibrating with bubbles

If the large-scale distribution of galaxies resembles the disposition of soap films in "the suds in the kitchen sink," as is compellingly indicated by Valerie de Lapparent, Margaret Geller and John Huchra's recent redshift survey (PHYSICS TODAY, May, page 17), we may eventually be afforded new handles on the old cosmological problems of the distance scale, expansion rate and global curvature of the universe.

Attempts to infer the cosmological distances of remote objects from their brightnesses or redshifts have remained uncertain owing to the possibility that the distribution of luminosities of objects or the rate of global expansion may have varied with the age of the universe. (What we see at great distances are necessarily in the remote past.) However, if we make the usual cosmological assumption that the Earth does not occupy a privileged position, then the sharply bounded cells or "bubbles" within which luminous galaxies are virtually absent should not on the average be elongated in directions that are systematically oriented with respect to their direction from the Earth. By fitting ellipsoids (or, in two-dimensional slices, ellipses) to the boundaries of apparently empty cells in surveys of the sort reported by de Lapparent, Geller and Huchra, we should eventually be able to use any systematic elongations or compressions along radial directions from the Earth to determine what correction of the distance scale, if any, is needed at each redshift to render the principal axes of the ellipsoids equal or, at least, uncorrelated with radial direction from the Earth.

Any residual dependence on distance of the average size of the cells would then furnish evidence concerning secular trends in the sizes of these cells over cosmological time.

Finally, for all cells within a given range of redshifts, the extent to which the average number of cells sharing a boundary with each individual cell deviates below or above 12 (the close packing number for Euclidean space) would indicate the extent to which the global curvature of the universe at the corresponding temporal epoch was positive or negative, respectively.

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That ol' dark matter

The news story on the "bubbly universe" (May, page 17) needs some additional clarification. Three primary theories are discussed in trying to account for this structure: primordial explosions, cold dark matter and hot dark matter (also called the "pancake theory"). Unfortunately, the interviews included in the theoretical section of the story quoted only proponents of the first two models. This may be related to the fact that Yakov Zel'dovich's group in the USSR is primarily associated with the third model, which is an appropriate one if any of the three(?) neutrinos has a small but finite mass.

Such models are often studied by numerical simulation. It is unknown whether such large voids as the bubbly universe appears to contain can form in the primordial explosion model by propagating explosions. The cold dark matter model does not produce large voids naturally. It is possible to reinterpret the model so as to cause some voids to appear; they of course must appear extremely commonly, as they seem to in the observational data. Note