tive views of the NASA microgravity research program. It is suggested that metrics such as "good scientific value for the money" and "cost-per-science" be used to evaluate the program. This concept alone requires a response, but particularly so because a conversation that I had with him needs to be clarified.

In the next to last paragraph of the article, it would seem that I am endorsing the view that "good science" is hard to obtain by means of the quotes attributed to me—that "[t]here is precious little time in space for experiments" and that "it is also hard to repeat and alter experiments and to publish papers based on only one data set." In fact, I was responding to the view that very little worthwhile science has been done in Spacelab missions. My point was that the shuttle has been used for many different purposes and that there has been relatively little available total time for the research community to do microgravity research. I have been fortunate to have had sufficient time for my experiments, and that research led to the awarding of seven Ph.D. and five M.S. degrees and the publication of 22 papers.

With respect to the issue of metrics, which some want to apply to the microgravity research program, I would challenge these individuals to indicate to what other research programs such metrics were applied and used as justification. How does one determine the dollar value of a science program? When Charles Townes was doing his pioneering work on lasers, did anyone, at that time, have any idea of the many applications of that work? Yes, space research is expensive, but so are many other research programs.

Lawler also says that "even [Spacelab's] supporters acknowledge there have been no major breakthroughs" in the program. Despite the relatively little experimental time allotted to microgravity research, a great deal of knowledge has been obtained about the behavior of fluids in that unusual environment. There are few, if any, other research programs that have yielded more scientific information from so little experimental time.

Microgravity research is of intrinsic scientific value in that it explores fluid and transport phenomena in an unusual environment, not unlike the ultra-high vacuum, high-magnetic field, and cryogenic environments that are used in other scientific fields. In addition, microgravity research is important because fluid and transport phenomena are inherent in many biophysicochemical systems and, therefore, it not only provides a knowledge base for the design of efficient and reliable space technologies but also can give insight into complex phenomena in industrial processes.

As more flight experiment time becomes available to a broader research community on the international space station, the exciting potential of microgravity research will be more readily achieved.

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Response: Ostrach does not appear to dispute that Spacelab provided limited experiment time for researchers and has yet to result in a major scientific breakthrough—two points accepted by program critics and supporters alike. His belief that worthwhile science has been done on the shuttle is expressed in depth by several in the article. As for the cost of science, Townes did not conduct his work in an era of the Government Performance and Results Act. All taxpayer-funded research programs by law must begin to measure their effectiveness, which clearly poses a daunting challenge for physicists as well as for life and microgravity scientists.

—*Andrew Lawler*

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Global Temperature Patterns

On reading the Research commentary "It was the best of times, it was the worst of times" by P. Jones (*Science*'s Compass, 24 Apr., p. 544), the reader might see more disagreement than actually exists between that piece and a recent paper by Mann *et al.* (*1*). We take this opportunity to clarify some possible misunderstandings. The point expressed in the piece by Jones regarding the need for extensive and independent cross-validation of proxy-based reconstructions is indeed one that is wholly embraced by Mann *et al.* (*1*). The Northern Hemisphere mean temperature series shown in (*1*) is based on the calibrations which exhibited the greatest skill, that is, the fraction of instrumental variance described in both calibration and cross-validation or "verification." This reconstruction was based on all available data, which included proxy data, and the few long instrumental and historical records. However, a variety of additional independent calibration-verification experiments, although not shown, were clearly referred to in (*1*) and are described in detail on *Nature*'s supplementary information Web site (*2*), referred to by Mann *et al.* (*1*) In several of these experiments, only true "proxies," that is, natural archives, were used in the temperature pattern reconstructions. The long historical and instrumental records dating back several centuries in Europe and North America were withheld from the calibration experiment. These data were then used for just the kind of independent long-term verification advocated by Jones for all paleoclimate reconstruction studies. Those tests demonstrated that pure proxy-based reconstructions of global surface temperatures were able to reproduce quite faithfully the actual instrumental temperature records that are available several centuries back in time [a dozen in Europe and western Asia, and one in North America—see (2)]. We all advocate strongly the independent verification of proxy-based climate reconstructions by the use of long instrumental and historical data, withheld from the calibration, for independent long-term cross-validation.

The comparison shown by Jones between Mann *et al.*'s Northern Hemisphere temperature reconstruction (*1*) and two other recent estimates is useful in several ways. For example, it demonstrates the robustness of the conclusion that the 20th-century warming is unusual in the context of the past several centuries, on the basis of largely independent estimates. However, the comparison might be misleading to those readers unfamiliar with the details of seasonal and spatial sampling contributing to the different estimates. Apparent discrepancies between these different estimates are largely associated with these sampling differences. The Mann *et al.* series represents estimated annual calendar-mean conditions and a spatial average over the entire—tropical and extratropical—Northern Hemisphere. The other two series shown in (*1*) represent estimated warm-season half-year conditions with a more extratropical Northern Hemisphere emphasis in the data used. As mentioned (*1*), certain proxies, like tree-ring density data, are highly effective indicators of warm-season temperatures. This makes warm-season temperatures the logical quantity to reconstruct with such data when used alone. In contrast, the analysis described by Mann *et al.* (*1*) attempted to exploit the complementary seasonal information in a diverse set of proxy, instrumental, and historical indicators. The statistical calibration-verification experiments performed in that study indicated that annual mean conditions could be more accurately represented than warm- or cold-season half-year conditions. More work is needed to resolve the seasonal details of climatic variability in past centuries. A key aim of future efforts must be to further improve multiproxy networks to both extend reconstructions of global climate further back in time, and to reduce uncertainties in existing estimates. As we decrease present uncertainties [represented, for example, by the substantial error bars shown for the Mann *et al.* reconstruction (*1*), or the differences between independent warm-season temperature estimates shown in the piece by Jones], it is to be hoped that we will soon be able to better constrain patterns of climate variability in past centuries. Such improved constraint will aid us in verifying important aspects of the numerical climate models now used to describe possible future climate scenarios.

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References and Notes

1. M. E. Mann, R. S. Bradley, M. K. Hughes, *Nature* **392**, 779 (1998); see also G. Hegerl, *ibid.*, p. 758.
2. Data are available through *Nature*'s World Wide Web site (http:/www.nature.com) or from Mary Sheehan at the London editorial office of *Nature*.