fessionals in the more abstract sciences should accept the fact that their fellow citizens haven't a clue what all those weird equations mean, will never use them, and basically couldn't care less.

Pity the poor abstract theologians, who have had the same problem for millennia. Religious leaders were a different breed. They never used abstractions; they just told real life stories (for example, Jesus' rabbinical parables on the good Samaritan or the prodigal son, or the battle stage in the Hindu epic *Mahabharata*).

If physicists want citizens to learn science, they should start with things the average citizen can observe repeatedly with as many senses as possible—especially touch.

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Riordan replies: The question of what is "real" has been debated—and will continue to be debated—by philosophers for centuries. If nothing is real except for observations, as Richard Henry states in his last sentence, then quantum mechanics itself must not be real or true. Therefore, his strict empiricist conclusion rests on very shaky ground.

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SQUIDs Remain Best Tools for Measuring Brain's Magnetic Field

The uninformed reader might be misled into believing that optical magnetometers (see PHYSICS TODAY, July 2003, page 21) will soon displace SQUIDs for biomagnetic measurements. I have spent 30 years using superconducting quantum interference device (SQUID) magnetometers and miniature induction-coil magnetometers to measure biomagnetic fields with ever-increasing spatial resolution. Several significant obstacles lie between optical magnetometers and high-resolution measurements of the brain's magnetic field.[1]

Several points are worthy of careful analysis. First, the typically reported sensitivity of SQUIDs, 1 fT/Hz$^{1/2}$, is not a fundamental limit set by the Josephson effect, but a practical one. One must consider thermal (Johnson and thermoelectric) noise within the Dewar flask and the object being studied; the object's intrinsic noise—for example, brain noise (thermal currents and background neural activity within the brain); fluctuations of magnetic shields; environmental magnetic noise; the desired spatial resolution; and the dynamic range of the electronics. SQUID sensitivities of nearly 10^{-17} T/Hz$^{1/2}$ have been reported.[2] With the exception of SQUID microscopy, more sensitive SQUIDs are not generally needed for biomagnetism, because the existing ones have reached the noise floor set by the Dewar, the object being studied, or the environment.

Because superconducting pickup coils can either trap or exclude magnetic flux, SQUIDs have the tremendous advantage of being able to measure femtotesla magnetic fields in the presence of tesla-strength steady fields and microtesla time-varying ones. A well-balanced SQUID gradiometer operating in the geomagnetic field can achieve a common mode rejection of up to 10^7. Electronic gradiometry allows high-quality SQUID recordings of the adult and fetal magnetoencephalogram (MEG) in unshielded laboratories.[3]

The magnetic shields and cancellation coils needed for the Kominis optical magnetometer reduce the external magnetic field by a factor of 10^6, four orders of magnitude greater than the shielding factor of approximately 200 for the standard magnetically shielded rooms often used for biomagnetic measurements. That both the optical magnetometer and the object producing the magnetic signals have to operate in such a low magnetic field is a severe practical constraint, such that Kominis and colleagues[1] suggest using superconducting magnetic shields to reduce "the overall noise of the magnetometer."

The most important point missed in the discussion of the recent optical advance is that the ability of any magnetometer to discriminate between two adjacent sources, such as a pair of cortical columns (modules), is determined not only by the size of the magnetometer but also by the cortex–magnetometer separation. A good rule of thumb is that the magnetometer size and the source-to-sample distance should be approximately equal, lest the spatial resolution of a small magnetometer be blurred by a large separation. To record the MEG from the intact brain, the cortex-to-magnetometer separation would be at least 1 cm—the skull thickness. Hence, millimeter-sized magnetometers would provide little additional benefit.

To be competitive with current commercial SQUID MEG instruments, the magnetic field would have to be measured at about 300 separate locations on the surface of the skull, and ideally more than one field component would be measured. At a minimum, the field component perpendicular to the skull would be needed, which means that each normal-component magnetometer would be measuring the field in a different direction, complicating the control and readouts for optical magnetometers. Although multichannel SQUID MEG systems can already localize a single cortical dipole current source to within a millimeter, many clinically significant MEG sources are distributed over 10 cm^2 or more. An optical magnetometer with submillimeter spatial resolution could be used effectively only if the cortical column being measured were a comparable distance from the magnetometer. That would require removal of the skull—readily achieved in whole-animal or brain-slice preparations, but not achieved noninvasively. Finally, the optical magnetometer operates in a 180°C oven, and noiselessly protecting a 37°C brain from a hot magnetometer may be harder than from a –270°C SQUID, since a warm Dewar may be a lot noisier than a cold one!

SQUIDs are regularly recording the MEG, and the magnetometer cost is only a small fraction of the cost of a clinical MEG facility. SQUIDs are already within striking distance of the cortical column: Microscopes with a 4-K, 100-μm SQUID now operate 100 μm from biological tissue.[4] The sensitivity continues to improve: A new 40×40-μm SQUID sensor has less than 1 pT/$Hz^{1/2}$ noise and is well matched to the 60 pT field predicted to exist 50 μm from a single cortical column, according to Franz Baudenbacher of Vanderbilt University.

I applaud the continued development of optical magnetometers. These devices offer interesting prospects for two-dimensional imaging and fundamental measurements, but it is premature to consider their replacing SQUIDs for most applications.

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US Research and Engineering Jobs Are Moving Overseas

The article on the research workforce (PHYSICS TODAY, August 2003, page 26) argues that more American scientists and engineers are needed for the "future of the country's research and engineering workforce."

Much of US manufacturing and, increasingly, services such as engineering design, information technology support, technical writing, and call or help centers have moved overseas in pursuit of significantly cheaper labor. Many US companies have sharply reduced or eliminated their R&D departments to cut costs and to improve their quarterly earnings.

So who is going to hire all these additional scientists and engineers for the US workforce?

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Corrections

August 2003, page 62—Bryce DeWitt is also a new fellow of the American Academy of Arts and Sciences.

January 2004, page 35—For reference 2, the correct Web address for D. Rumsfeld et al., executive summary of the *Report of the Commission to Assess the Ballistic Missile Threat to the United States* is http://fas.org/irp/threat/missile/rumsfeld/. The National Intelligence Council document *Foreign Missile Developments and the Ballistic Missile Threat Through* 2015 is available online at http://www.cia.gov/nic/other_missilethreat2001.html. ■