

Goethe and Land Provoke Colorful Comments

I found Neil Ribe and Friedrich Steinle's article "Exploratory Experimentation: Goethe, Land, and Color Theory" in the July 2002 issue of *PHYSICS TODAY* (page 43) both stimulating and provoking. Like all good articles, it raised as many questions in my mind as it posed answers.

Consider Isaac Newton's "color circle," shown in Ribe and Steinle's figure 1. How did Newton ever get the idea of representing a continuum of colors on a circle? Surely painters had long known that mixing a bit of red with a bit of blue produces violet (or indigo). But what theoretical justification could Newton have posed for wrapping the diagram and joining it along a line (D in the figure) between red and violet? That step does not seem to be supported by his observations with light.

His observations did suggest to Newton that color values appear on a continuum, rather than as shown in Johann Wolfgang von Goethe's simplified picture. Newton's empirical chart is not greatly different from the modern CIE chromaticity diagram, based on sensory stimuli, in which the greens and yellows occupy almost half the area.

Newton's color wheel suggests to me a kind of empiricism just as bold as Goethe's. I agree with the authors' characterization of "exploratory experimentation," but I believe such investigation plays an even larger role in science than they suggest. All productive research is carried out within some sort of theoretical framework; the difference between the traditional model and the "exploratory" or "empirical" model is only in the degree to which experiments are guided by theory. Karl Popper's idea that experiments should be wholly guided by theory is useful, but it does not embrace the notion of progress—except as ad-

vanced solely by theorists. Thomas Kuhn's understanding of scientific revolutions, on the other hand, suggests that all revolutionary ideas are formulated outside the bounds of current theory. Many great discoveries, particularly in astronomy and cosmology, have come about through a stretching of the limits of theory.

I can find no better example of the difference between the traditional model and the "exploratory" model than the article on magnetic confinement of fusion plasmas by Richard Hazeltine and Stewart Prager in the same issue of *PHYSICS TODAY* (page 30). Perhaps someone long ago said, "Construct a magnetic bottle, and it will contain a magnetized plasma indefinitely," but theory provides little guidance on exactly how the bottle should be constructed. Fantastic geometries such as those shown in the figures on pages 33 and 35 did not spring directly from theoretical reasoning. They took countless hours, over many decades, of tweaking the parameters, just as Newton, Goethe, and Edwin Land arrived at their ideas of the colors seen by the eye.

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Neil Ribe and Friedrich Steinle seem to believe that Edwin Land and Johann Wolfgang von Goethe made unprecedented contributions. In fact, both simply presented to innocent audiences already recognized visual phenomena¹ in very accessible and highly dramatic forms. In Goethe's day, the scientific bases of these phenomena were still not completely understood, and Goethe's artistic characterization of them may have modestly inhibited fuller understanding. But by the time that Land and his stagehands went about giving extraordinarily elaborate public demonstrations of basic color phenomena, a first approximation account had been given for both the perceptual and neural bases of color perception. Unfortunately, few members of Land's audiences apparently had previously visited any well-equipped color vision laboratory.

Ribe and Steinle's presentation is also problematic outside the domain

of color when they ascribe to Land a special appreciation of the importance of boundaries in the eye's estimation of lightness. If one leaves aside the contributions of nonphysicists, Ernst Mach's name is as indelibly associated with his 19th-century work on edge contrast effects (now known as Mach bands) in vision² as it is with the speed of sound.

References

1. See, for example, my book, G. S. Wasserman, *Color Vision: An Historical Introduction*, Wiley, New York (1978).
2. E. Mach, *Contributions to the Analysis of the Sensations*, reprint ed., C. M. Williams, trans., Open Court, Chicago (2000).

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Workshops Work for High-School Physics Teachers

Howard Birnbaum's article, "A Personal Reflection on University Research Funding" (*PHYSICS TODAY*, March 2002, page 49) and letters responding to it (August 2002, page 12) discussed outreach requirements for NSF grants. I hope that summer workshops for high-school teachers remain an acceptable outreach mechanism.

In my state, high-school physics teachers are effectively required to take summer workshops. Physics teachers hunger for a little more content than many summer workshops provide. If we college physics teachers do not provide that content, we have abandoned our high-school teachers.

I had previously opposed workshops on principle, because they were offered as graduate work but did not measure up to serious graduate course standards. Now, I'm much less concerned about that situation. I urge physicists to overlook the fake graduate credit issue and offer their expertise and experience to an audience that has a real appetite for physics. I've given three one-week workshops, and estimate that they

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