LETTERS TO THE EDITOR

Letters are selected for their expected interest for our readers. Some letters are sent to reviewers for advice; some are accepted or declined by the editor without review. Letters must be brief and may be edited, subject to the author's approval of significant changes. Although some comments on published articles and notes may be appropriate as letters, most such comments are reviewed according to a special procedure and appear, if accepted, in the Notes and Discussions section. (See the "Statement of Editorial Policy" at http://www.kzoo.edu/ajp/docs/edpolicy.html.) Running controversies among letter writers will not be published.

COMMENT ON "SCHOOL MATH BOOKS, NONSENSE, AND THE NATIONAL SCIENCE FOUNDATION," BY DAVID KLEIN [AM. J. PHYS. 75 (2), 101–102 (2007)]

> How we understand the mind matters… it matters for what we value in ourselves and others—for education, for research, for the way we set up human institutions, and most important for what counts as a humane way to live and act… Our ideas about what people can learn and should be learning, as well as what they should be doing with what they learn, depend on our concept of learning itself. It is important that we have discovered that learning for the most part is neither rote learning nor the learning of mechanical procedures. It is important that we have discovered that rational thought goes well beyond the literal and the mechanical.
>
> -Lakoff[1]

In a recent editorial in the *American Journal of Physics*,[2] David Klein, a mathematician, derides mathematics curricula sponsored by the NSF and the majority of mathematics education research along with it. He cites examples of theorems that are not explicitly taught, formulas that are not memorized, a lack of textbooks, on the one hand, and an incorrect problem from one textbook that is provided. He states seemingly unreasonable stances that guided the new materials (claiming "the goal for students to achieve fluency in algebra and arithmetic was often derided by educators"). Reading his letter, anyone with a stake in mathematics education would have to wonder what's going on: how could 20+ years of some of the best minds in mathematics and mathematics education create products that are seemingly so disastrous? Why would the NSF, filled with scientifically literate and mathematically fluent Ph.D.s, sponsor what Klein terms the "gravy train of education grants and awards that stifle competent mathematics education?" And how can we keep this from happening in science education?

It does not make sense for me to write a rebuttal to Klein's editorial addressing the first two questions; I am not in mathematics education, for one, and it has been done—repeatedly—for another. These rebuttals have come from the mathematics education research community,[3] from mathematicians with background and research in education,[4] and from cognitive scientists who study how the brain learns and understands mathematical concepts.[5] These rebuttals cite independent evidence, research from large scale studies, use measures aligned with the intent of the curricula, are consistent with findings from cognitive science, and describe the findings and goals that have shaped the NSF's approach to mathematics education.

Klein's editorial fails to do this: it focuses on superficial aspects of the curriculum (noting that students are not told how to do "long division, subtraction with borrowing, and the usual pencil-and-paper methods of multiplication," but failing to address whether or not students learn to divide, subtract, and multiply); when noting that TERC students are "two years behind where they should be" he cites a report by the Fordham Foundation that he coauthored. "Where they should be," it turns out, is not dictated by research on learning, but by the author's expectations of how calculators should be used, how number facts should be memorized, and how standard algorithms should be introduced.[6] His criticism of an incorrect problem and solution in a reform textbook is not matched by a criticism of traditional coursework and assessment. When considering independent research, *the evidence is unambiguously in favor of NSF-sponsored reform*.[7]

So, instead, I want to address the question: "How can we keep this from happening in science education?" By "this" I do not mean misguided curricular reform (for I trust that the grant- and the peer-review process, together with careful assessment, limits that), but the misunderstanding of high-quality curricular reform, the failure to treat this reform as a product of research on learning, and the ensuing political wars that limit the adoption of effective curriculum and methods.

Schoenfeld[8] details how mathematics education got to this point and why the rhetoric surrounding mathematics education, such as that in Klein's editorial, has moved so far from traditional academic discourse. This rhetoric is usually confined to letters to local school boards, newspapers, and the political arena[9]—places where we might wish for scientific rigor but, in the name of free speech and the absence of peer-review, we have become accustomed to statements that generate more heat than light. However, when an editorial in AJP draws analogies between the skull-and-crossbones emblem on poison and the NSF logo on curriculum, calling the textbooks "some of the worst…in the industrialized world," it seems that the physics education research community should begin to look more closely at how the physics

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community at large understands and supports work in education, and how we present our research and curricula in physics education, that this rhetoric might not enter the physics education discourse.

This concern is not unfounded: the recent history of science education reform has had similar cries from scientists who, though well-intentioned, so criticized the proposed science standards for California and so clamored for "higher" standards[10] that now California fourth-grade students are to learn the very basics of magnetism (that magnets have a north and south pole), of electromagnetism (that currents produce magnetic fields), all the way through to the role of electromagnets in motors and generators, and how to construct them.[11] Second graders should "know the way to change how something is moving is by giving it a push or a pull. The size of the change is related to the strength, or the amount of force, of the push or pull." Second grade? Would that college students understood that the change—not the speed—is related to the strength of the force! What's more, research in education and cognitive science suggests that these standards are not achievable in a meaningful way by these students, at this age, in the amount of time available and with the background knowledge they bring. That is to say, students might be able to memorize these statements, but they will not be able to make sense of them, they will not understand the development of the ideas nor be able to reason creatively and flexibly using these ideas. Students are destined for failure, teachers are frustrated by another round of reforms, and those who added more "rigor" to the Standards can only wring their hands and wonder why no one is learning.

So how can science education research and reform avoid the wars and vitriol that mathematics education has not? To a large degree, we cannot: there will always be uninformed dissent from well-meaning scientists and parents; there will even be informed dissent, largely within the education research community but also from without, and the sides in this tug-of-war are often defined by differences in values, and values are rarely swayed by data. But to the degree that we can engage in scientific debate, basing our curriculum on research and understanding the underlying values and suppositions on which that curriculum is based, we should. I would like to encourage papers in physics education research to:

(1) Take education research, methods, and findings seriously. Understand that, when done well, education research is founded on a solid base of cognitive science, psychology, and previous education research. We should neither write nor positively review research articles that do not commit to a broad understanding of previous research on learning and explicitly situate themselves in this literature.
(2) Careful research and strong evidence should be made for educational goals that differ from the more easily assessed and more objectively defined "content" goals. Whenever possible, these goals and the rationale for and research behind them should be explicit. Criticisms of reform curricula, therefore, should find fault in the *research* that underlies the goals of that curricula instead of critiquing more superficial aspects (e.g., "they have no textbooks" or "they aren't using calculators").
(3) Understand the limits of research in assessing curricula. In physics, if two ideas are different, one of them is wrong. Education research is another matter entirely. Not only are goals hard to determine and harder still to assess, but determining those goals is a value-laden enterprise involving a setting of priorities. There are many dimensions to scientific thinking, and pitting these against one another, as if they were either/or, belies a naive understanding of education and learning.

Historically, physics education research held itself to a relatively behaviorist perspective: we looked at gains in scores as measures of improvement, speculated in private about the minds that were improving, and tended to steer clear of the less-understood aspects of scientific thinking in the assessment of our curriculum.[12] But as physics education research broadens its scope, builds on findings from cognitive science and psychology, and comes to understand key elements of scientific thinking (e.g., attention to student expectations,[13] epistemology,[14] and abilities[12]), I expect that the curriculum we create, topics we teach, and research we conduct will begin to move further away from traditional physics courses. Given the climate that exists in mathematics education, where shifting the emphasis towards reasoning becomes a battle cry that rallies opponents to rewrite well-researched curriculum and standards, we would do well to enter this territory cautiously and well-informed, and as openly and judiciously as we can.

[1] G. Lakoff, *Women, Fire and Dangerous Things: What categories reveal about the mind* (Univ. of Chicago, Chicago, IL, 1987).

[2] D. Klein, "School math books, nonsense, and the National Science Foundation," Am. J. Phys. **75**(2), 101–102 (2007).

[3] E.g., J. Kilpatrick, W. G. Martin, and D. Schifter, *A Research Companion to Principles and Standards for School Mathematics* (National Council of Teachers of Mathematics, Reston, VA, 2003). (In particular, the chapter by J. Hiebert, "What research says about the NCTM Standards," pp. 5–23.)

[4] E.g., A. H. Schoenfeld, "The math wars," Educ. Policy **18**(1), 253–286 (2004) and articles by Rosenstein at http://dimacs.rutgers.edu/%7Ejoer/articlesm.html

[5] R. Núñez, "Mathematical idea analysis: What embodied cognitive science can say about the human nature of mathematics," opening plenary address in *Proceedings of the 24th International Conference for the Psychology of Mathematics Education*, Hiroshima, Japan, Vol. 1, pp. 3–22.

[6] D. Klein, B. J. Braams, T. Parker, W. Quirk, W. Schmid, W. S. Wilson, C. E. Finn, Jr., J. Torres, L. Braden, and R. A. Raimi, "The State of Math Standards 2005," from http://www.edexcellence.net/foundation/publication/publication.cfm?id=338

[7] See, e.g., ARC Center, 2003. Full report of the tri-state student achievement study. Retrieved from www.comap.com/elementary/projects/arc/tri-state%20achievement%20full%20report.htm; S. Senk and D. Thompson (eds.) *Standards-oriented School Mathematics Curricula: What Does the Research Say about Student Outcomes?* (Erlbaum, Mahwah, NJ, 2003).

[8] A. H. Schoenfeld, "The math wars," Educ. Policy **18**(1), 253–286 (2004).

[9] Examples can be found on anti-mathematic education reform websites, such as http://www.mathematicallycorrect.com and http://www.nychold.com. (More moderate websites, such as http://mathematicallysane.com, give a more complete picture of the debates.)

[10] J. A. Bianchini and G. J. Kelly, "Challenges of standards-based reform: The example of California's science content standards and textbook adoption process," Sci. Educ. **87**(3), 378–389 (2003).

[11] The California Science Education Standards: http://www.cde.ca.gov/be/st/ss/scmain.asp. For examples of test items related to these standards (with occasional incorrect items in the answer key), see http://star.cde.ca.gov

[12] E. Etkina, A. Van Heuvelen, S. White-Brahmia, D. T. Brookes, M. Gentile, S. Murthy, D. Rosengrant, and A. Warren, "Scientific abilities and their assessment," Phys. Rev. ST Phys. Educ. Res. **2**, (1998).

[13] E. Redish, J. Saul, and R. Steinberg, "Student expectations in introductory physics," Am. J. Phys. **66**(3), 101–102 (2007).

[14] B. White, A. Elby, J. Frederiksen, and C. Schwarz, The Epistemological Beliefs Assessment for Physical Science, AERA Annual Meeting, Montreal, 1999.

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COMMENT ON "SCHOOL MATH BOOKS, NONSENSE, AND THE NATIONAL SCIENCE FOUNDATION," BY DAVID KLEIN [AM. J. PHYS. 75 (2), 101–102 (2007)]

Mathematics Professor David Klein (California State University, Northridge) presented an editorial in *Am. J. Phys.*, Vol. 75, No. 2, February 2007, titled "School math books, nonsense, and the National Science Foundation." As the Principal Investigator and Project Director for System-wide Change for All Learners and Educators (SCALE), the NSF comprehensive Math and Science Partnership (MSP) project mentioned in his editorial, I feel obliged to correct at least some of Professor Klein's misrepresentations.

Professor Klein cites SCALE as an example of a multimillion dollar grant awarded by NSF to distribute "'fuzzy math' programs" to schools. Professor Klein's assertion is a misrepresentation of the intent of the NSF MSP program and is false and misleading with respect to the SCALE MSP work.

First, some background. SCALE is a partnership of the major urban school districts in Denver, Madison (WI), Providence (RI), and Los Angeles, together with UW—Madison, California State University, Dominguez Hills (CSUDH), and California State University, Northridge (CSUN). SCALE's overarching goal is to improve K–12 math and science education, preservice math and science teacher preparation, and in-service math and science teacher professional development. The most important strategy for doing this is the key feature of the NSF MSP program—innovative partnerships among K–12 and postsecondary institutions, with substantive participation by science, technology, engineering, and mathematics (STEM) faculty. SCALE-supported work in mathematics in the Los Angeles Unified School District (LAUSD) includes promoting a new partnership comprising some CSUN mathematics faculty, CSUDH mathematics and mathematics education faculty, and LAUSD mathematics master teachers. This new partnership has provided three-week professional development institutes for middle school mathematics and high school algebra teachers. These institutes have been conducted at both CSUDH and CSUN. SCALE is doing parallel work in elementary and middle school science teacher professional development,[1] again through partnership of CSUN and CSUDH STEM and STEM education faculty, together with their LAUSD science colleagues.

Professor Klein claims that SCALE "promotes" three mathematics curricula—*Interactive Mathematics Program* (IMP), *Connected Mathematics Program* (CMP), and *TERC: Investigations in Number, Data, and Space* (TERC)—"even in California where those books are not state approved." As I indicated above, SCALE support is primarily through content-focused teacher professional development using the expertise of STEM faculty, STEM education faculty, and district professionals. In undertaking this work, SCALE supports the partner districts' curricula choices and, if requested, provides national expertise with regard to those choices. For example, in California, SCALE supports the state-adopted programs chosen by its district member, LAUSD. SCALE attempts to do this in ways that will help teachers use the district's curricula and other resources to advance the understanding and performance of district students, in alignment with the local and state standards that guide the district's curricular and professional development choices.

Since SCALE believes it is important in general to seek and then to provide evidence, and even more so when addressing a national audience, let me examine further Professor Klein's claim that "SCALE ***promotes*** [emphasis mine] IMP, CMP, and TERC." In a footnote, Professor Klein includes a SCALE website. On 7 February 2007, SCALE staff searched the entire SCALE website (http://scalemsp.wceruw.org/) for *IMP*, *CMP*, and *TERC* and found 13 hits. I invite the reader to do a similar search and decide which description of SCALE activities is more accurately described by this evidence: Professor Klein's claim that SCALE "promotes" these curricula, or mine that SCALE "supports" their use in districts that choose to use them.

Here is one example in detail (www.scalemsp.org/index.php?q=MMSD_Mathematics_Masters), describing the Madison Metropolitan School District (MMSD) Math Masters Program, a middle school mathematics professional development program that has been running in Madison for the last two and a half years:

> The first course sponsored by MMSD's Title II Wisconsin Math Science Partnership (MSP) Block Grant, tailored to support SCALE-aligned middle school math content instruction, begins August 2004 at the University of Wisconsin—Madison. The class focuses on statistics and probability, and claims UW—Madison Mathematics Department Chair Dr. David Griffeath as its instructor. Forty teachers from MMSD plus four surrounding school districts are registered. The course modules are designed to enable any teacher to produce proficient standards-based curriculum regardless of chosen textbook.
>
> Through the Math Masters project, the Madison Metro-

politan School District, School District of Beloit (SDB), School District of Juda (SDJ), Sauk Prairie School District (SPSD), and the University of Wisconsin—Madison Department of Mathematics (UW) will join forces to raise mathematics achievement via an ongoing, intensive, program of content-based teacher professional development that will bring the partners' middle school mathematics teachers together in courses taught by UW—Madison mathematicians and applied mathematicians. In addition to content knowledge, teachers will receive content-specific pedagogical instruction and other forms of pedagogical support and modeling that will help them create standards-based mathematics classrooms and effectively utilize the "Connected Mathematics Project" (CMP) curriculum.

> The goal of the project is to increase middle school students' achievement in mathematics by strengthening the quality of mathematics instruction through the provision of content-based professional development linked to Wisconsin's Model Academic Standards for Mathematics and professional development on high leverage research-based strategies to develop student understanding. Project objectives are: 1) to increase the content knowledge of 150 middle school mathematics teachers; 2) to improve these teachers' understanding of how students learn mathematics; and, 3) to enhance implementation of the CMP curriculum within participating teachers' classrooms.

This statistics and probability course was the first of what became six content area courses for the Math Masters Program. Professor Griffeath, former chair of the UW—Madison Mathematics Department, is one of six professors (five from mathematics, one from mechanical engineering) who have participated in the program. CMP is the district-adopted middle school math curriculum. Note that the goals of the Math Masters Program include helping teachers "effectively utilize the 'Connected Mathematics Project' (CMP) curriculum" and "enhance implementation of the CMP curriculum within participating teachers' classrooms." These are the references to CMP at this URL. This SCALE-related work is intended to support the districts' curricula choice in middle school mathematics, not to promote a particular mathematics curriculum. This SCALE support is intended to increase the content mastery of the teachers so that they can better serve their students' learning needs.

NSF is providing MSP funding to allow cross-institutional and cross-disciplinary teams to explore and design new forms of partnership that might help solve the difficult and complex problems of improving math and science education in this country. This is a discovery process—something that is at the heart of the NSF mission. Based on early evidence, I believe SCALE has made measurable gains. I venture that the CSUDH and CSUN administrations believe this too, as the provosts at those two institutions are SCALE co-PIs.

The role and nature of curricula in math and science education are important issues and worthy of close scrutiny by stakeholders representing different perspectives and expertise. In the spirit of partnership, it would be advantageous if contributors to these important national discussions were accurate in their details and representations. I personally believe that new kinds of partnerships across traditional disciplinary and institutional boundaries—the key concept in the NSF Math and Science Partnership initiative—hold great promise for improving math and science education at all levels. And I also believe that these new partnerships should focus on challenges, and approaches to those challenges, that unite rather than divide.

It is my opinion that Dr. Klein's response to this letter does not advance the claim he made in his original editorial that SCALE distributes or promotes particular mathematical curricula. We also disagree with his newly introduced opinions of SCALE work at CSU Northridge. These opinions (that do not address the issues of "promote and distribute") are just that, they are not based on a systematic evaluation of the SCALE teacher professional development program (and we note that the chair of his department and his provost support this SCALE work).

[1] For an example of SCALE science immersion, see J. Folsom, Catherine Hunt, Maria Cavicchio, Anne Schoenemann, and Matthew D'Amato, "How Do You Know That? Guiding early elementary students to develop evidence-based explanations about animals," Sci. Child. **44**(5), 20–25 (2007).

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REPLY TO COMMENTS ON "SCHOOL MATH BOOKS, NONSENSE, AND THE NATIONAL SCIENCE FOUNDATION," BY DAVID KLEIN [AM. J. PHYS. 75 (2), 101–102 (2007)]

Professor Millar objects to my use of the word "promotes" in this statement from my editorial:

> In addition to other activities, SCALE promotes IMP, CMP, and TERC even in California where those books are not state approved. These textbooks lack the mathematical content necessary to meet the state's K–12 math standards.

According to Dr. Millar, "SCALE-related work is intended to support the district's curricula choice in middle school mathematics, not to promote a particular mathematics curriculum." Yet, the 2005 conference co-sponsored by SCALE held in Los Angeles featured as one of the keynote speakers, Diane Resek, co-author of *Interactive Mathematics Program* (IMP). Her address, "Challenging Courses and Curriculum," included a downloadable powerpoint show that presented data in support of the effectiveness of IMP. Another presentation at that conference, "Physics and Algebra for all 9th Graders" praised TERC and CMP as "challenging curricula." None of the conference materials made reference to any California state adopted textbooks or programs, aligned to the state's math standards.[1]

Professor Millar also refers to the SCALE-supported three-week professional development institutes held at my institution, CSUN. I reviewed documents used for the algebra institute. Among them was an article presenting data favorable to IMP.[2] One and a half weeks of the institute were devoted to mathematical topics, and the balance to preparing lesson plans. Material from IMP was used for the mathematical topics part of the three-week course, but there was no material for that purpose from California approved textbooks. The mathematical content was pitched at the low end of high school math. The focus was on patterns and *ad hoc* methods, with little actual algebra involved. Missing were mathematical proofs or even the development of technical fluency. Nevertheless, teacher participants who completed the three-week workshop were awarded three units of graduate credit in *mathematics* (not mathematics education) at CSUDH. The net result is that the $35 million NSF-funded SCALE project not only promotes defective mathematics programs, not aligned to California's demanding math standards, it drags down standards for graduate work in mathematics in the California State University system.

Unfortunately, SCALE is not unique. Similar criticisms could be directed toward many other programs funded by the Education and Human Resources (EHR) Division of the NSF.[3] For more than a decade, EHR has contributed to the dumbing-down of K–12 mathematics education in the United States by funding the creation, promotion, and distribution of inferior math textbooks, and training teachers to use them.

Dr. Atkins asks, "how can science education research and reform avoid the wars and vitriol that mathematics education has not?" She charges critics of controversial math textbooks with a "misunderstanding of high-quality curricular reform, [and] the failure to treat this reform as a product of research on learning." Pressing her case, she writes, "shifting the emphasis towards reasoning becomes a battle cry that rallies opponents to rewrite well-researched curriculum and standards…" To avoid these problems in science education, Dr. Atkins advises, "take education research, methods, and findings seriously."

Dr. Atkins' charge that opponents of questionable math books don't like them because those books emphasize reasoning is improbable. Leading mathematicians criticize the so-called "well-researched curricul[a] and standards" for a dearth of reasoning and lack of content.

Mathematicians are not alone. Well-informed parents have not been persuaded by educational researchers to subject their children to these low-content programs. Physicians, lawyers, engineers, scientists, and other parents across the country strenuously oppose NSF-funded textbooks for their own children. If there was substance to the advocacy research supporting these deeply flawed programs, parents would be flocking to expose their children to them. Instead, parents are fleeing *en masse*. Atkins listed two websites for parents groups opposed to "fuzzy math," but there are many others and their numbers are increasing.[4]

Dr. Atkin's faith in educational research is not uniformly held by other experts. A committee of the National Research Council issued a report in 2004 that evaluated the reliability of education research studies of curricular programs in mathematics.[5] From the executive summary: "this committee's charge was to evaluate the quality of the evaluations of the 13 mathematics curriculum materials supported by the National Science Foundation (NSF) (an estimated $93 million) and six of the commercially generated mathematics curriculum materials." The committee "concluded that the corpus of evaluation studies as a whole across the 19 programs studied does not permit one to determine the effectiveness of individual programs with a high degree of certainty, due to the restricted number of studies for any particular curriculum, limitations in the array of methods used, and the uneven quality of the studies."

Dr. Atkin's use of the word "reform" should be considered in historical context. For the past century, mathematics education has been in a perpetual state of "reform" by educational experts.[6] The controversies surrounding the subject, now and in the past, are more similar than different, but each new generation of educationists presents well-worn ideologies as if they were new and revolutionary.[7] Dr. Atkins' admonition to "take education research, methods, and findings seriously" should therefore be taken with a grain of salt.[8]

[1] See: ⟨scalemsp.wceruw.org/IHEConference2005/main.htm⟩

[2] J. Boaler and M. Staples, *Transforming Student's lives Through an Equitable Mathematics Approach: The Case of Railside School*, preprint ⟨www.sussex.ac.uk/education/documents/boaler_2_-_creating_mathematical_futures.pdf⟩.

[3] See, for example, M. McKeown *et al.*, "National science foundation systemic initiatives: how a small amount of federal money promotes ill-designed mathematics and science programs in K–12 and undermines local control of education," Chap. 13 in Sandra Stotsky (ed.), *What's at Stake in the K–12 Standards Wars: A Primer for Educational Policy Makers* (Peter Lang, New York, 2000), pp. 313–369. ⟨www.csun.edu/~vcmth00m/chap13.pdf⟩

[4] Web pages for parents' groups such as the following (and many others) are easily found through an Internet search: "Mathematically Correct," "New York City Honest and Open Logical Debate," "Where's the Math?," "Illinois Loop," "Parents Concerned With Penfields Math Programs," "Teach Utah Kids," "Connected Mathematics, Disconnected Parents," "Kitchen Table Math," "Save Our Children from Mediocre Math."

[5] Mathematical Sciences Education Board, *On Evaluating Curricular Effectiveness: Judging the Quality of K–12 Mathematics Evaluations*, Committee for a Review of the Evaluation Data on the Effectiveness of NSF-Supported and Commercially Generated Mathematics Curriculum Materials, National Research Council of The National Academies (The National Academies, Washington, DC, 2004). ⟨books.nap.edu/openbook.php?record_id=11025&page=R1⟩.

[6]David Klein, "A Brief History of American K–12 Mathematics Education in the 20th Century," Chap. 7 in *Mathematical Cognition: A Volume in Current Perspectives on Cognition, Learning, and Instruction*, edited by James Royer (Information Age, Greenwich, 2003), pp. 175–225. ⟨www.csun.edu/~vcmth00m/AHistory.html⟩
[7]David Klein, "A quarter century of US 'math wars' and political partisanship," BSHM Bulletin: Journal of the British Society for the History of Mathematics, **22**(1), 22–33 (2007). ⟨www.csun.edu/~vcmth00m/bshm.html⟩
[8]For an example of shortcomings in a particular study, see "A Case Study: An email debate on the quality of education research in mainstream education journals between Dr. Pendred Noyce, head of the Noyce Foundation, and David Klein focusing on the article, 'The impact of two standards-based mathematics curricula on student achievement in Massachusetts,' J. E. Riordan and P. E. Noyce, J. Res. Math. Educ. **3**(4), 368–398 (2001). ⟨www.csun.edu/~vcmth00m/noyce.htm⟩

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EARTH ROTATION VIA DOPPLER SHIFTS?

Bernal and Bilbao[1] measure rotation of a mirror up to 300 rpm by reflecting a green He-Ne laser beam, mixing it with a part of the source beam and determining the Doppler shift from the Fourier transform of the interference pattern. They mention that it might be possible to use their method to measure the Earth's rotation. The Sagnac effect (the beats obtained when mixing CW and CCW beams in a rotating polygonal interferometer) has been interpreted as the anisotropy effect of cumulative Doppler shifts due to reflection from moving mirrors.[2] The measurement of the Earth's rotation via the Sagnac effect dates from 1925,[3] and with lasers it is now routine.[4,5] Our most recent machine has an area of 833.7 m^2 and a perimeter of 121.4 m (filling our cavern laboratory). Due to the Earth's rotation, the mixing of the CW and CCW beams induces a signal at 2.177 kHz.

[1]Luis Bernal and Luis Bilbao, "Optical doppler shift measurement using a rotating mirror," Am. J. Phys. **75**, 216–219 (2007).
[2]M. Dresden and C. N. Yang, "Phase shift in a rotating neutron or optical interferometer," Phys. Rev. D **20**, 1846–1848 (1979).
[3]A. A. Michelson, H. G. Gale, and F. Pearson, "The effect of earth's rotation on the velocity of light," Astrophys. J. **61**, 137–145 (1925).
[4]R. Anderson, H. R. Bilger, and G. E. Stedman, "Sagnac effect: a century of earth-rotated interferometers," Am. J. Phys. **62**, 975–985 (1994).
[5]G. E. Stedman, "Ring laser tests of fundamental physics and geophysics," Rep. Prog. Phys. **60**, 615–688 (1997).

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AUTHOR'S REPLY

Stedman cites many successfully experiments regarding the measurement of the Earth's rotation via the Sagnac effect. He addresses the important fact that Sagnac measurements can be interpreted as a Doppler effect. In a rotating interferometer all optical components are moving, and therefore each one produces a Doppler shift. Accounting for the total contribution of all the mirrors, the standard Sagnac formula is recovered.

We want to clarify the fact that we referred to the value of the Earth's rotational rate as an example of what we call low rotational speed rather than a proposal to measure the Earth's rotation by means of our apparatus. As suggested by a reviewer, one could mount the mirror on a motorized rotation stage and move it very slowly. Our apparatus may be used to show students how to detect very low rotational speeds.

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