Towards an increased understanding of educational reform.

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> 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 curriculum 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, and an incorrect problem and solution from one textbook. 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 article 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. The evidence, in fact, is unambiguously in favor of NSF-sponsored reform[6].

Instead, I want to address the question that keeps me up at night: "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 assessment and cognitive science, safeguards against that, as it does in mathematics), but misunderstanding and misrepresentation of high-quality curricular reform and the ensuing political wars that limit the adoption of effective curriculum and methods.

Schoenfeld[7] 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[8] -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 a lot of heat and little light. However, when an editorial in the 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 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 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[9]. 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"[10]. 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 we work to construct a foundation in science education research that avoids 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[11], 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. Care, precision and strong evidence should be made for educational goals that differ from the easily assessed, more objectively defined and more traditional "content" goals.

3. By that same token, science education research must hold itself to the highest standards of scientific fact. Imprecision and incorrectness -

which sneak into the unlikeliest of places - make otherwise illuminating and interesting research easily dismissed.[1]

4. Celebrate diversity. Appreciate quality research with educational aims different from your own. Understand that no test captures the whole of a student's scientific knowledge and abilities, and curriculum and tests designed to align with certain aspects of scientific reasoning will not provide meaningful feedback on curriculum designed to align with other aspects.

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.[2], 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 an emphasis on 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.

References

[1] Lakoff, G., *Women, Fire and Dangerous Things: What categories reveal about the mind.* Chicago, Illinois: The University of Chicago Press, 1987.

[2] Klein, D. "School math books, nonsense, and the National Science Foundation," *American Journal of Physics*, **75 (2)**, 2006?, 101-102.

[1]That is not to say that physics education must have unassailable scientific fact as its only (or even primary) goal, rather that, in reporting research, readers should not doubt the author's grasp of the scientific ideas.

[2]Attention to student expectations (the Maryland Physics Expectations Survey), epistemology (Epistemological Beliefs Assessment for Physical Science), abilities[12], analogies (Podolefsky and Finklestein, Atkins), and mechanistic reasoning (Russ, Hammer and Scherr) all call for a deeper understanding of and instruction that improves upon scientific abilities/habits of mind.

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

[4] E.g., Schoenfeld, A.H. (2004). The math wars. Educational Policy, v. 18 no.1 253-286; and articles by Rosenstein at http://dimacs.rutgers.edu/%7Ejoer/articlesm.html.

[5] Núñez, R. "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*, **1:3-22**. Hiroshima, Japan.

[6] See, e.g., ARC Center, 2003. Full report of the tri-state student achievement studey. Retrieved from `www.comap.com/elementary/projects/arc/tri-state%20achievement%20full%20report.htm`; Senk, S., and Thompson, D. (eds) (2003). Standards-oriented school mathematics curricula: what does the research say about student outcomes? Mahwah, NJ: Lawrence Erlbaum.

[7] Schoenfeld, A.H. "The math wars." *Educational Policy*, **18(1)**, 2004. 253-286.

[8] 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.)

[9] The California Science Education Standards: `http://www.cde.ca.gov/be/st/ss/scmain.asp`

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

[11] Rosen, L. "Calculating concerns: The politics of representation in California's "math wars."" Unpublished doctoral dissertation. University of California, San Diego. 2000.

[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**, 020103, 2006.