Motorcycle Maintenance and the Art of Physics Appreciation

FEATURE

by Dwight E. Neuenschwander

How many people driving a car every day carry in their minds a mental image of the mechanics, thermodynamics, and electromagnetism that make their machine possible? Our society is saturated with technological applications of science. Yet most people you encounter in the laser-equipped grocery store checkout line, waiting in the clinic for their MRI, or sitting next to you on the airplane, seem amazingly uncurious about how any of this stuff works. How quickly the marvelous becomes commonplace and taken for granted!

Some perceptible progress has been made towards science being claimed as the intellectual heritage of everyone. Practically everybody has some mental picture of the Earth as a planet orbiting a star, agrees that human genetics gets encoded in helical molecules, and assumes that floods and earthquakes have geophysical causes. But although science has revealed a breathtaking vision of the universe and our place in it, here again the typical citizen, by and large, seems unreflective about it all. How quickly the astonishing becomes mundane! Henry David Thoreau exaggerated only mildly when he lamented that[1]

Nature has no human inhabitant who appreciates her...

Why this lack of wonder and curiosity? It does not start out this way. I have evidence to suggest that second and third graders are the world's most promising scientists. Wonder and curiosity about the physical world bubble forth as spontaneously from them as their desire to play. For years my university's chapter of the Society of Physics Students has conducted “physics circuses” with local elementary schools. Working with their teachers, we invite the children to submit written questions in advance. The 2nd and 3rd graders ask the same kinds of profound questions that drive fundamental scientific research. Here is a sample, in their own spellings:[2]

What makes light?
— Christy

How can the planets obet the sun
when they’re on nothing?
— Robby

1 how does the sun stay up?
2 how does the wrod move urand?
3 how does trees grow??
4 how did dinosarze live?
— Michael

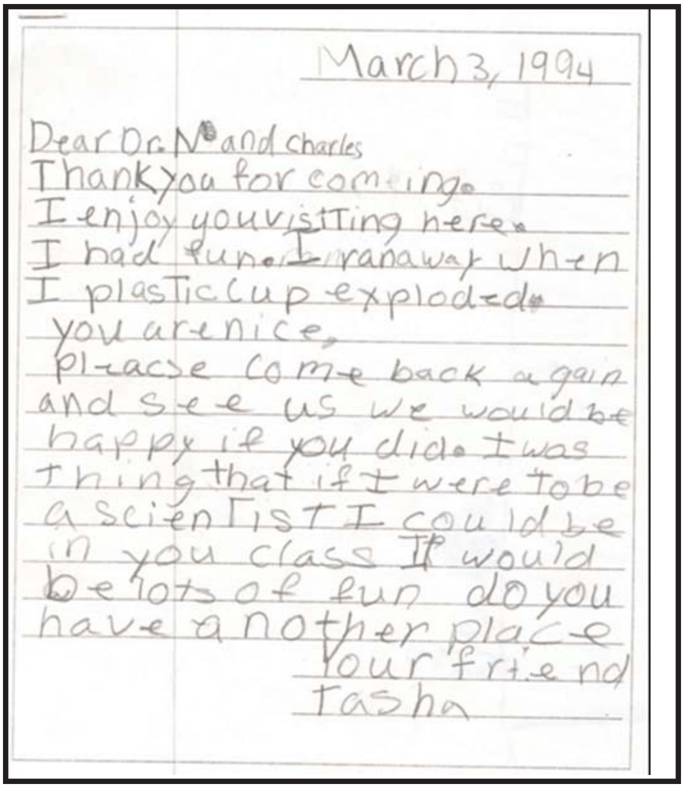
I wont too how gravtae wroks. and how
doss the sun shin. and how mene stars are
thar in the hol wrlld.
— Kevin

I want to know if space ever ends, how magnets work, how lightning acrus, how electricity works, how sound works, if numbers ever end, how clowds acru.
— Chris

how dus the electricity gite throw the plug?
— Nikki

The thank-you letter from Tasha.

All photos appearing in this article are courtesy of the author.



March 3, 1994
Dear Dr. N and Charles
Thank you for coming.
I enjoy you visitting here.
I had fun. I ranaway when
I plastic cup exploded.
you are nice.
Pleacse come back again
and see us we would be
happy if you did. I was
thing that if I were to be
a scientist I could be
in you class It would
be lots of fun do you
have another place
Your friend
Tasha

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All photos in thi

Why are all people different?
— Erin

These are the same questions that drive fundamental research in science! Our Einsteins, Curies, and Feynmans never stopped asking such "childish" questions. Thoreau said,[3]

Children, who play life, discern its true law and relations more clearly than men, who fail to live it worthily, but who think that they are wiser by experience, that is, by failure.

The minstrels sang as much a century later:[4]

Watch children playing,
They seem so wise.

These delightful little people also write revealing thank you letters. From a class of third graders:

I really enjoyed your show. I liked it when the liquid exploded. I like when the chemical changed. How did you think about being a scientist. A few days ago I was thinking and I got some food and made an experiment but it turned brown. The same day I made an experiment with milk and my mom told me to pour it out.
— Your friend, Christina.

Our "physics circus" with six second-grade classes at Northridge Elementary School, Oklahoma City, OK. We were told that we would not be able to hold the attention of 120 wiggling second graders for 50 minutes. We had no problem. They were filled with questions.

...Please come back again and see us. We would be happy if you did. I was thinking that if I were to be a scientist I could be in your class. It would be lots of fun. Do you have another place?
— Your friend, Tasha

We hope that Christina will keep on experimenting. We hope that Tasha will still want to be a scientist when she reaches college. But we know that, statistically, they will not. Among the many difficulties that Christina and Tasha must overcome to keep their curiosity alive, two of the most formidable may grow from their first impressions of science as a formal academic subject.

One of these obstacles is the perception, often verbalized to children before they can decide for themselves, that "Science is *hard*." The abilities of these same children to learn languages and music suggests that the "hardness" of science is overrated, and may be a symptom of other issues in the educational process. That question we must set aside for another day.

The second obstacle, and the one explored here, is the early impression that science is *dull*. "Dull" is more serious than "difficult."

Most of us were probably introduced to formal science around the sixth grade, when we met some form of a checklist Scientific Method. A contemporary version of it goes like this:[5]

Using Scientific Methods
1. Ask a question.
2. Make a hypothesis.
3. Plan a fair test.
4. Do your test.
5. Collect and record data.
6. Tell your conclusions.
7. Go further.

Such a checklist has value in emphasizing that science thinking must be organized so that you know what you know, and know what you don't know. But when such checklists morph into science as catechism, they give the false impression of science as a stern schoolmaster. Interest and curiosity are the first casualties. But this dour view of science does not square with the experience of practicing scientists. Most scientists see their work as an expedition filled with adventure and creativity. Their work is closer to that of the artist, and not the building inspector.

In 1974 Robert Pirsig chronicled in *Zen and the Art of Motorcycle Maintenance* a trip he took with his son Chris.[6] Beneath the surface was a philosophical journey as well. While visiting a friend who was a sculptor at Montana State University, Pirsig was shown a set of rotisserie assembly instructions. The professor of sculpture had spent a frustrating afternoon putting the rotisserie together, and wanted to see the instructions thoroughly damned. Finding nothing technically wrong, Pirsig took a broader view and said,[7]

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Our young colleagues help us enjoy ice cream made with liquid nitrogen.

What's really angering about these instructions is that they imply there's only one way to put this rotisserie together—their way. And that presumption wipes out all the creativity....

Science is not done by checklists of rigid rules. Not coincidentally, the same may be said of art. In *The Story of Art*, E.H. Gombrich put it this way:[8]

It is fascinating to watch an artist...striving to achieve the right balance, but if we were to ask him why he did this or changed that, he might not be able to tell us. He does not follow any fixed rules. He just feels his way. It is true that some artists or critics in certain periods have tried to formulate laws of their art; but it always turned out that poor artists did not achieve anything when trying to apply these laws, while great masters could break them and yet achieve a new kind of harmony no one had thought of before.

Science appreciation is not about following rigid rules. It's about creativity. It's about relationships. Returning to the rotisserie instructions, Pirsig continued:[9]

[It] presumes there's just one right way to do things and there never is....But if you have to choose among an infinite number of ways to put it together then the relation of the machine to you and... to the rest of the world, has to be considered, because the selection from among many choices, the art of the work, is just as dependent upon your own mind and spirit as it is upon the material of the machine...

Those second graders wanted to know what makes the sun shine, if space ever ends, if numbers ever end. These are the same questions that drove Hans Bethe and Albert Einstein and Emmy Nöether.[10] But instead of an adventure in discovery, our budding scientists got a checklist. Checklists can be tested for on a quiz.[11] The spirit of adventure was trumped by another agenda. What happens when you have to wear somebody else's mind and spirit? Pirsig recalled how his former self, referred to in the third person as Phaedrus, began teaching rhetoric at Montana State:[12]

He was working on lecture notes at the time and was in a state of complete depression about them....

The text started with the premise that... rhetoric...should be taught as a branch of reason.... Elementary logic was introduced,... stimulus-response theory was brought in, and from these a progression was made to an understanding of how to develop an essay...

[Phaedrus] felt there was something wrong with it...He... felt that no writer ever learned to write by this squarish, by the numbers, objective, methodical approach....

Then one day Sarah, the department secretary, said in passing, "I hope you are teaching Quality to your students." Phaedrus assured her that he was. But the more he thought about it, the more he realized he could not answer the question, "What *is* Quality?" You *recognize* Quality when you see it, but you can't *define* it. Since you can't define it, you can't fit it into a structured system. That realization started Phaedrus on a long philosophical journey that took him past the point of madness. A motorcycle illustrates the principles.[13]

Teachers always wish their students were as engaged as this audience! How can their curiosity about the world be kept alive until they acquire the ability to handle abstract concepts?

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Near Pie Town, NM. Robert Pirsig observed that "In a car you're always in a compartment, and because you're used to it you don't realize that through that car window everything you see is just more TV. You're a passive observer and it is all moving by you boringly in a frame. On a cycle the frame is gone. You're completely in contact with it all. You're in the scene, not just watching it anymore, and the sense of presence is over-whelming." (Pirsig, ref. 6, p. 12).

Motorcycles function according to the rules of reason. One way therefore to understand a motorcycle is through the logical analysis of its systems, with wiring diagrams and maintenance schedules. Pirsig called this world of underlying form the "Classic" mode of understanding. This way of seeing a motorcycle is essential when your alternator burns out. But there's also the "Romantic" mode of understanding. Here one appreciates surface impressions-the motorcycle's rugged grace, the gleam of the chrome, the joy of riding.

An apparent split between science and art seems to follow this Classic-Romantic fault line. Pirsig saw this split as destructive, and tried to bring the two modes of understanding together. As he and others have observed, this apparent split goes back to the beginning of Western thought.[14,15] The Greek philosophers were seeking what is *true*, above mere opinion. In the competition for the mind of mankind, they opposed the Sophist teachers of rhetoric, who taught *excellence*, one's judgement of what is *good*. The philosophers thought it necessary to introduce a distance between object and subject. Pirsig saw this detachment as the source of the disconnect between modern society and the natural world, between people and their machines and one another. Landscapes and wildlife become commodities; the sky is over us but we never look up; persons become objects, science a list of numbered instructions.

The link between the Classic and Romantic ways of seeing, the source of both, is Quality. Your search for what's *true* is guided by your sense of oneness with what's *good*. That guidance, that oneness, cannot be reduced to rotisserie instructions.

How does this guidance work? To maintain a motorcycle or to do physics, you must observe facts. But when the motorcycle won't start, or when your students are profoundly stumped by Faraday's law, you don't sit back and *passively* observe facts. *Which* facts are you going to observe? The color of the gas tank? The student's zip codes? The facts that are worth observing have to be *selected* on the basis of value.[16]

And Step Two of the checklist Scientific Method says "Make hypothesis." Although you can make an infinite number of hypotheses, you can never test them all, even though the checklist says you must. Therefore you have to reject some hypotheses in advance, through value considerations such as simplicity and elegance. The logic of science rests on a foundation of *aesthetic* values.

This reality has long been understood by master artists of physics, from Henri Poincaré writing about the selection of facts in 1908,[17] to George Sudarshan contrasting metaphors and analogies, laws and principles in 1998.[18] In a 1918 speech, Albert Einstein noted that the supreme task of science is to arrive at universal elementary laws that describe nature.[19] But, said Einstein,

There is no logical path to those laws; only intuition, resting on sympathetic understanding of experience, can reach them...

Einstein was talking about something deeper than reason: the *art* of doing physics. Combining intuition with evidence based reasoning, science is the art of creating and testing a network of concepts in terms of which the universe becomes comprehensible. Those concepts are creations of the human mind. That's the art. They must be tested against reality, then modified or replaced as necessary. That's the science. One cannot teach this craftsmanship, or gain a feeling for the work, by following fearfully the rotisserie instructions.

Pirsig observed how the true artist follows wherever Quality leads, even when the Quality path departs from the instructions. "*Sometime look at a novice workman or a bad workman and compare his expression with that of a craftsman whose work you know is excellent... The craftsman isn't ever following a single line of instruction. He's making decisions as he goes along....The material and his thoughts are changing together in a progression of changes until his mind is at rest at the same time the material's right."*[20]

Where does the "objectivity" of science come in? It will not be found in the attitude of an Einstein pursuing his vision, for 10 difficult years, of gravitation as the curvature of spacetime. Objectivity will not be found in a Marie Curie standing day after day over noxious vats of melted pitch-

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Dusk at the VLA, July 2006.

blende relentlessly pursuing trace amounts of radioactive elements. No, the objectivity of science does not go on pristine display in the focused dedication of the intense researcher.[21] It enters through the integrity of peer review, the rebar that gives the structure of science its robust strength. Passion for the craftsmanship drives the artist-researcher; skepticism drives the reviewer. When their minds meet, they are engaged in a conversation with Nature.

Craftsmanship requires the absence of detachment and the presence of authenticity. As Thoreau observed,[22]

It is a vulgar error to suppose that you have tasted huckleberries who never plucked them.

Authenticity in art or science begins with re-creating the work in the appreciator's own mind. In his 1956 essays *Science and Human Values*, Jacob Bronowski described *two* moments in the creative process:[23]

The poem or the discovery exists in two moments of vision: the moment of appreciation as much as that of creation;.... When...a theory is at once fresh and convincing, we do not merely nod over someone else's work. We reenact the creative act, and we ourselves make the discovery again.

This second creative event in physics does not always require one to learn vector calculus. It can be as direct as addressing the simple but fundamental question: "What are we doing when we solve a physics problem?" One answers, The art of physics compares the world of concepts to the world of empirical reality. But what does that mean for, say, the well-used textbook example of the block on the inclined plane?

We do not apply Newton's laws to a block on an inclined plane. We apply Newton's laws to a *conceptual representation* of a block on an inclined plane. The block is modeled as a particle, and its interactions with the rest of the world are modeled as forces and potential energies. Acceleration, mass, the particle, gravitational field, force, and energy are *concepts* that correspond to real world observables. The art of doing physics invents conceptual models, then compares their inferences against the real systems they are supposed to approximate.[24,25] This process, like the conceptualization and building and testing of a new motorcycle, stands a long way from the literal recitation of rules.

As Robert Pirsig said to Chris, taking care of a motorcycle is not hard if you have the right attitudes. It's having the right attitudes that's hard.[26] In today's society many of our fellow citizens assume science to be just another belief option. As physics appreciators we bear a responsibility to help them discover why science does not worship authority. The spirit of science says, "Is that so, eh? What's the *evidence*?" Reciting the evidence is easy; cultivating an environment where one has eyes to see it is hard, as the ongoing public conversation about greenhouse gases and climate change amply demonstrates.[27] Or to cite another contemporary example: whether or not the universe was designed by a cosmic intelligence, the question is meaningless *as science* because it invokes explanations that stand outside of nature. Science deals in explanations that operate *within* nature. Why is that central point so hard to get across to a public that starts looking for the nearest tower when fretting over cell phone reception?

Which brings us to everyday relevance in the appreciation of the familiar. The most engaging activity I have ever done with a class has each student dissect a cadaver. Unlike the biologists, we put our cadavers back together. I refer to my "Engine Cadaver Lab" (see photos).[28] I don't know who has the most fun doing it, me or the students! Working in small groups, the students take apart and reassemble lawn mower engines. We examine how the engine applies physics concepts, from the moment of inertia of the flywheel to Faraday induction in the magneto; we compare systems in the human body to their engine analogs;[29] we learn what 5 ft-lbs of torque *feels* like; we visualize how a real engine actually works. As one who grew up tinkering with cars and motorcycles, I continually have to be reminded that few students today have ever worked on their own machines, even though they depend on them every day. What happened to the curiosity that so animated them as second graders twelve years before?

Happily, our engine cadaver lab, more than any other single activity I have ever done with students, gets them talking with animation. It also provides an opening for sobering discussions about the environmental impact of hundreds of millions of engines operating daily on our planet. We are *part* of the Earth, not detached spectators of it.

The photo on the cover of this issue of *Radiations* carries for me a summary of what a life with science appreciation is all about. While on a motorcycle trip from Arizona

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to Oklahoma, I pulled into the Very Large Array one evening at dusk. There I had the New Mexico desert all to myself. The vast silence was profound. The fading rays of sunlight painted the clouds as the first stars came out. I was not looking *at* the landscape; I was *in* it. Thoreau felt it too:[30]

I have, as it were, my own sun and moon and stars, and a little world all to myself...Why should I feel lonely? It not our planet in the Milky Way?

I stood there for a long time, gazing into the sky, absorbing the solitude, alone without loneliness. There sat the machine that carried me so effortlessly across mountains and deserts; behind it another machine silently gathered faint signals from a galaxy halfway across the universe. Romantic awareness of earth and sky and light; Classical appreciation of the underlying forms that made possible the astronomical habitat, desert life, and the machines. It was a moment to live in and take with me always. It's not about the destination. It's about the journey. I wished Tasha were there. I wanted to say to her, Yes, we have a place for you here. Come and play.

— Dwight E. Neuenschwander, Editor

Scenes from our engine cadaver lab.

We tear the engines down to the crankshaft and put them back together. We do not restore the engines to running condition, but they do have to be complete and "turn over" freely.

Notes

This article borrows excerpts from two of the author's talks, "Conversations with ghosts" (*Am. J. Phys.* **69** (3), 251-254 (2001), presented at the Summer 2000 AAPT Summer meeting; and "There is no 'Art,' there are only artists," <http://preview.tinyurl.com/23taj2>, presented at the Summer 2006 AAPT meeting.

References

[1] Henry David Thoreau, *Walden* (first published in 1854, my copy by Houghton Mifflin Co., 1960), p. 138.
[2] Questions from pupils in the second and third grade classes of Northridge Elementary School, the second grade of Wiley Post School, and Bethany Elementary School, all in the Oklahoma City area. These samples of questions were gathered in the early and mid 1990s. Tasha has probably graduated from college by now. I wonder if she became a scientist?
[3] Thoreau, Ref. 1, p. 66.
[4] Lyric excerpt from "The Morning," track 3 of *Days of Future Passed* by the Moody Blues (Decca Records, 1967).
[5] This checklist comes from *Scott Foresman Science*, Vol. 4 (Pearson Education Inc., 2007), p. 312.
[6] Robert M. Pirsig, *Zen and the Art of Motorcycle Maintenance* (William Morrow & Co., 1974, 1999).
[7] Pirsig, Ref. 5, pp. 166-167.
[8] E. F. Gombrich, *The Story of Art* (15th Ed., Phaidon, 1995), p. 35.
[9] Pirsig, pp. 166-167.
[10] Hans Bethe first worked out in 1938 the nuclear reactions that power the Sun; in 1917 Einstein published the first modern cosmological model, featuring a closed, finite universe, a paper that started a discussion that led twelve years later to the genesis of big bang cosmology; in 1918 Emmy Nöether published what is now called "Nöether's Theorem" that relates conservation laws to symmetries. Nöether was well known to mathematicians for her work on abstract algebra.
[11] I mean this literally. On my son's first day of sixth grade, when he had his first middle school science class, he was given a checklist "scientific method" and instructed to memorize it for the next day's quiz. I'm a PhD physicist and don't have the checklist memorized, so why sixth graders had any real reason to memorize it escapes me. It was reduced to fodder for a quiz, and therefore made the first whack at detaching that former second grade scientist from the authentic practice of science, just as he was learning the conceptual frameworks that would allow him to answer some of those profound second grader's questions. It seems that the making of such guidelines by the students themselves, *after* they have put a question to nature and have some experience to reflect over, would be more meaningful than having The Method presented as it were on tablets of stone.
[12] Pirsig, pp. 180–182.
[13] ibid., pp. 73–74
[14] ibid., pp. 371–375.
[15] George Kennedy, *The Art of Persuasion in Greece* (Princeton University Press, 1963), Ch. 1.
[16] Pirsig, p. 281.
[17] Henri Poincaré, *Science and Method* (1908, Barnes & Noble, 2004).
[18] Tony Rothman and George Sudarshan, *Doubt and Certainty* (Basic Books, 1998).
[19] Albert Einstein, "Principles of Research," address delivered at a celebration of Max Planck's 60th birthday, 1918. Reprinted in *Ideas and Opinions* (Crown Publishers, 1954, 1982), pp. 224–227.
[20] Pirsig, pp. 166–167.

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More engine cadaver lab scenes .

To obtain the engines, I sent a mass e-mailing to the faculty and asked for "dead" gasoline-powered lawn mowers, and said "Give it a new life as a cadaver for general physics lab." I immediately received over a dozen engines.

More engine cadaver lab scenes .

We take three to four lab periods for the engine cadaver lab and its accompanying discussions.

[21] Of course, the craftsman physicist practices internal "peer review" before sending the paper to the editor. One may be motivated by the beauty of one's idea, but like the builder of a motorcycle prototype, one rides it hard to see where it will break in order to fix that weakness. For a thorough and recent example of this process, see W. M. Wood-Vassey et. al, "Observational Constraints on the Nature of Dark Energy: First Cosmological Results from the ESSENCE Supernova Survey" (*Ap. J.* 666: 694-715, Sept. 10, 2007). The group describes their understanding of systematic error sources and estimates the contribution of each one, in a section called "Sources of Systematic Error." These include bias in differential image photometry, CCD linearity, photometric zero-point calibrations, bandpass uncertainty, K-corrections (transforming the magnitude in the observed filter to the magnitude in the rest-frame filter), galactic extinction, biased selection effects, supernova evolution, gravitational lensing, "gray" dust, and others. Even the most passionate researcher, if a true craftsman, puts hard questions to his or her own work, anticipating problems and answering them, before the work ever goes to external peer review. But to describe this important caveat in the text would have broken up the flow of its point.

[22] Thoreau, p. 120.

[23] Jacob Bronowski, *Science and Human Values* (Harper, 1956, 1965), p. 19.

[24] ibid, Ch. 2.

[25] David Hestenes, "Modeling Games in the Newtonian World," *Am. J. Phys.* 60 (8), 732-748 (1992).

[26] Pirsig, p. 410.

[27] Sharon Begley, "The Truth About Denial," *Newsweek*, August 13, 2007, pp. 20-29.

[28] "Engine Cadaver Lab" poster presentation, AAPT Summer 2003 meeting, Madison, WI.

[29] For example, the engine analog to the respiratory system includes the air cleaner, intake manifold, etc.

[30] Thoreau, pp. 90, 92.

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THE DIRECTOR'S CORNER

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issues such as making physics more welcoming to all, hindering the effects of bias, financial aid issues, child care/family leave issues, non-traditional physics career trajectories, the importance of competent, diverse mentoring;

2) to provide participants (both actual and virtual) with authoritative documentation of the current climate for under-represented groups in physics;

3) to facilitate inter-organizational cooperation in addressing diversity issues in physics; and

4) to produce a statement in support of diversity in physics for adoption by SPS, preferably brief and potent.

Typically, over a dozen SPS zone meetings are held throughout the year, and part of the plan is to provide extra support for meeting organizers to hold a diversity workshop/ quiz show as part of the meeting. These regional meetings, some of which are traditionally held jointly with sectional meetings of AAPT and APS, will lead up to the Sigma Pi Sigma Quadrennial Congress to be held on November 7-8, 2008, at FermiLab, IL, where a culminating diversity event will be held.

Join us in celebrating diversity in the Future Faces of Physics at a zone meeting near you!

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