Physics for ALL requires Teachers to have 10 Years of Deliberate Practice: Why and How

By Jane Jackson

Theme: Everyone is a Physicist!

Jane Jackson's 15-minute talk for PoLS-T Network Annual Virtual Conference
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On YouTube: www.youtube.com/watch?v=eoDzvuTgUdo

The PoLS-T Network is an NSF grant of Eric Mazur at Harvard University to support high school physics teachers worldwide, because physics is crucial to civilization. It began in 2020.

Abstract: Physics for ALL requires that we teachers have 10 years of Deliberate Practice, to learn deep content and how to teach it effectively, so that students will enjoy physics so much that they'll want to keep learning it all their lives, and so that they'll convince other students to take physics. K. Anders Ericsson has studied development of expertise in a wide variety of endeavors. His conclusions are: it takes typically 10 years of DELIBERATE practice; that is, examining your performance, asking how you can improve it, and then taking specific steps to improve. That's our purpose in Modeling Workshops. But follow the money! Professional development (PD) has declined, due to the Federal government ending crucial PD programs. Chief among them for physics PD was the 2.5% set-aside for higher education grants for local PD, in the U.S. Department of Education Title II-A formula grants to each state. We must work to re-instate an automatic state set-aside, and target it for STEM teachers.

The talk (enhanced a little here, to explain things better):
Everyone is in some sense a physicist; we all encounter physics every day and everywhere. Every time we move! And gravity, of course. Studying physics increases our awareness of how the world (the universe) works. It's practical in daily life, enhancing our ability to do all sorts of endeavors, from kitchen to garden to garage to sports field and beyond. Thus, physics should be for ALL.

Physics for all requires that we teachers have 10 years of deliberate practice, to learn deep content and how to teach it effectively, so that students will enjoy physics so much that they'll want to keep learning it all their lives, and so that they'll convince other students in their high school to take physics. As Eugenia Etkina said on June 19 to the PoLS-T Network: young people are natural learners; and we need to enhance this, in ways that she described in her talk -- including thinking like a physicist; evidence-based thinking; building and refining scientific models; system thinking; and flow experiences. Eugenia's *Investigative Science Learning Environment* (ISLE and PUM) are super-compatible with Modeling Instruction. Physics teachers need PD in these two outstanding programs. (Eugenia's June 19 discussion is at https://www.youtube.com/watch?v=mg9ryJya9Ng . A link to her June 16 talk is there: https://www.youtube.com/watch?v=ldr1cOk8wGE)

I'm going to touch on legislation, so I speak in this talk as a private citizen. My views are my own. In this talk I don't represent any institution or organization.

What's troubling is that science teacher professional development (PD) has declined in recent years. Horizon Research documented the decline. (Trends in U.S. Science Education from 2012 to 2018, by P. Sean Smith. 2020, Horizon Research, Inc. https://eric.ed.gov/?id=ED611301)

Why has it declined? Because the Federal government ended crucial PD programs, making PD much too expensive. Chief among the programs that served physics teachers was the U.S. Department of Education's 2.5% set-aside for colleges (institutions of higher education – IHEs) in their formula Title II-A grants to each state. That provided $1 million to Arizona, each year, for teacher PD.

We must work to re-instate an automatic higher education set-aside for states, and target it for STEM teachers; that seems to be the easiest approach to increase free local PD opportunities, because it involves simply amending a few paragraphs of existing legislation.

But first, why do we teachers need 10 years of deliberate practice, to become experts? I quote David Hestenes, co-founder of Modeling Instruction. In 1995 to 2000 he had a huge NSF grant for Leadership Modeling Workshops for 200 expert teachers nationwide. He said to a group of 50 of them, in their 3rd summer at ASU in 1997, the following:

Back in 1985 we published the first data on the Mechanics Diagnostic Test, a precursor to the Force Concept Inventory (FCI). Malcolm Wells was the first person to apply this test to his high school class. His gains were low; his mean posttest score was about 45%, which we now know is typical for traditional physics instruction. But this was an epiphany for him, because he had put in tremendous effort at improving his instruction, and he was using most of the activities and general approach that you are using: photogates and computers -- yet he got these gains which weren't good. (Malcolm Wells didn't have "a natural gift" for teaching, by the way, but he worked very hard on refining his technique.)

However, by the time he finished his dissertation, 3 years later, he made a BIG gain, among the highest FCI gains ever achieved! … This example shows that it is definitely possible to improve considerably. …

Researcher K. Anders Ericsson has studied development of expertise in a wide variety of activities, from chess-playing and concert playing to performance in many fields of endeavor. He doesn't talk specifically about teaching. But he comes up with some general features of those people who become expert. They are universal across the different domains. Let me review the main points.

The first point is that IT TAKES A LONG TIME TO BECOME EXPERT in any complex domain. In fact, the time period is about 10 years. Consider a person devoting all his

time to playing chess. He may be a young prodigy or start later; there is an advantage to starting young, but it still takes 10 years before you can perform at the level of the outstanding experts. This is documented in areas where we have explicit data on performance. There is every reason to believe that it applies to teaching as well.

But 10 years isn't enough by itself. Another of Ericsson's conclusions is that experience doesn't necessarily produce improvement. So just because you have 10 years of teaching, it doesn't mean that you are any better a teacher than you were when you started out. In fact, with respect to concert playing with musical instruments, he has data that show that just performing in concerts doesn't improve your skill.

What DOES improve your skill? It is what Ericsson calls DELIBERATE PRACTICE and that is EXAMINATION OF YOUR OWN PERFORMANCE AND ASKING HOW YOU CAN IMPROVE IT, AND THEN TAKING SPECIFIC STEPS TO IMPROVE. That's what WE'RE trying to help you do in the Modeling Workshops! DELIBERATE PRACTICE over 10 years is as necessary to become an expert in teaching as in any other field.

(Hestenes Lectures on Modeling Instruction. Part 1: Expertise in Teaching; Significance of Force Concept Inventory (1997, unpublished. http://modeling.asu.edu/modeling/HestenesLectures/1.Expertise.pdf)
See also section 5: Cultivation of Teaching Expertise, in A MODELING METHOD for high school physics instruction, by Malcolm Wells, David Hestenes & Gregg Swackhamer. American Journal of Physics, July 1995. http://modeling.asu.edu/R&E/ModelingMethod-Physics_1995.pdf. A newer version is Appendix III. A picture in 2018 is at http://modeling.asu.edu/MNS/PHS542-DavidHestenes&GeoffClarion2018.png)

Did you know about K. Anders Ericsson's research? I had no idea, when I was teaching physics. I wish I'd known; it would have motivated me to seek in-depth PD. I would have been a better teacher!

In David Hestenes' NSF grant, the 200 physics teachers gave the Force Concept Inventory as a baseline posttest to their students before they took their first 4-week summer Modeling Workshop, and then after the workshops as pretests and posttests. Results showed that Modeling Instruction is highly effective pedagogy; its effect size is large: 0.9, satisfying the *What Works Clearinghouse* standard for effectiveness. Modeling Workshops are deliberate practice!
(See http://modeling.asu.edu/R&E/FCI-LargeEffectSize.htm)

I have 23 years of experience writing grants for physics Modeling Workshops. I have ideas on how the physics teacher community can work to restore affordable PD that's deliberate practice – working toward our vision of **physics for all**. Here's my story.

In addition to overseeing the 200 teachers in Leadership Modeling Workshops, I wrote grants yearly since 1998, for Arizona teachers to have summer Modeling workshops at ASU. Until 2005, I got $50,000/year in the Federal Title II-A *Eisenhower Math and Science Professional Development program* of the U.S. Department of Education. Each year I served 2 dozen physics & physical science teachers. Teachers got stipends and free ASU tuition. Enrollment increased, sometimes a LOT! The effect size was huge, with these teachers.

In general, Eisenhower grants were $50,000, and the entire state of Arizona was served in 15 to 20 grants each year, by faculty at Arizona's 3 universities who were passionate about science. Faculty volunteered, hosting up to 25 teachers each; the Eisenhower program worked well. *(Appendix I is an overview.)

In 2000, David Hestenes got another NSF grant to expand Modeling Workshops to other states. So, in addition to my Arizona PD work, I built an informal network of 2 dozen college physics faculty in 18 states, and I helped them get Eisenhower grants for Modeling Workshops in their locale. These grants were typically $50,000. Some of the 200 teachers in David Hestenes' first NSF grant led the workshops; in fact, they recruited the faculty. The workshops helped alleviate the nationwide shortage of qualified high school physics teachers. The faculty are listed at our website, modeling.asu.edu . (at http://modeling.asu.edu/Partners.htm). **

The Eisenhower program was replaced by 2004 with the Title II-A "Improving Teacher Quality" program in "No Child Left Behind" (Elementary & Secondary Education Act – ESEA). Unfortunately, the PD focus was broadened (diluted) to all core subjects in K-12, and further diluted by adding PD for principals. Some states chose to narrow it to focus on high-poverty school districts – disregarding the extreme shortage of physics teachers at schools of ALL socioeconomic levels. These changes made the program worse for physics. (Appendix II is an overview.)

Grants got bigger and fewer, and less money went to teachers. (More money went to administration and evaluation). It became harder for physics faculty to get grants, (They were all VOLUNTEERS -- this is important!). The result was disastrous for physics teacher PD in some locales – for example, St. Louis, Missouri, where the professor was denied funding because not enough of his physics participants taught in high-poverty schools. Within a few years, hardly any physics faculty could get grants from the "Improving Teacher Quality" program.

At ASU, we thrived until 2010: our yearly grant at ASU increased in 2006 to ~$250,000 for 100 teachers -- but I could no longer do the work as a volunteer, because I had to add chemistry and junior high physical science to get the grant, so my workload got too big. It's an inefficient use of funds! (I had to hire administrative staff -- hard to get, because short-term. Risky – in one- or two-year grants, staff aren't assured of job continuation. Job training slows down the work. You must act fast when you get a grant.) Our 5 summers of Modeling Workshops produced 80 highly qualified teachers from those who were teaching out-of-field, and highly qualified teachers became more effective.

After 2010, we at ASU were cut out of the grant process, because the AZ Board of Regents decided to fund ONLY math in one year, and only elementary school PRINCIPALs in another year. They were running scared, because by 2010, the Federal government was threatening to end the "Improving Teacher Quality" program, so the AZ

grant managers wanted the biggest bang for the buck: they wanted to improve the math test scores statewide, since math was high-stakes but science wasn't.

By 2015, only Ohio was still able to get "Improving Teacher Quality" funding. (Ohio had a wise higher ed agency, who recognized the long-term systemic need for physics.) But in December 2015 the *Improving Teacher Quality* program ended. "No Child Left Behind" was replaced by ESSA, the "Every Student Succeeds Act'. The 2.5% set-aside ended, period. Ohio Modeling Workshop enrollment in physics went from 100 down to zero, in the space of a year. Nothing.

The Federal government provides NO money now, for colleges to organize PD for teachers. Instead of teachers getting a stipend, they must pay almost $800 for a 3-week summer Modeling Workshop hosted by the American Modeling Teachers Association, AMTA. This is too expensive for many public school teachers to pay out-of-pocket, and their schools don't have enough Title II-A funds to pay. So private school teachers are predominant participants. (See https://www.modelinginstruction.org. You can read relevant excerpts of the ESSA Title II-A legislation at http://modeling.asu.edu/modeling/ESSA-TitleII-STEMtchrPD.htm)

What about us at ASU? For the past 10 years, we've existed on donations from local businesses -- a very time-consuming process, and donations are much LESS than $50,000 – typically $15,000 for 50 to 60 teachers. Few corporations give, and (with a few exceptions like Salt River Project and ON Semiconductor) they don't give much. It is foolish of the Federal government to rely on corporate gifts for teacher PD. I work almost full-time but there is no grant to pay me, so most of my work is volunteer. We had to stop offering PD in physical science, because recruiting 8th & 9th grade teachers was too hard, since they got no stipend, no tuition waiver. Free tuition is a powerful incentive!

At ASU, teachers must PAY $400 for our Modeling Workshops, for non-credit. Or if they want ASU graduate credit, they must pay $2200 tuition/ course. To help them, I write grants to local companies each year – and get typically $15,000 in donations. It is time-consuming and unproductive. I couldn't even convince my bank to give $1000 this year.

BOTTOM LINE: no program is left from the Federal government, to fund summer professional development for physics teachers. This bodes ill for the nation's future economy, since high school physics is the chief pathway to STEM careers and STEM majors in college.

Looking more widely, we need thinkers in this nation, as Eugenia Etkina said. Everyone is in some sense a physicist; we all encounter physics every day and everywhere. And societally, we must face the global climate crisis. What kind of world will young people inherit? Sea rise, extreme drought, vast fires, huge migrations – you know. To slow this devastation, we need to love the physical planet, our only home, so that we'll honor and preserve its resources. Love encompasses and includes understanding. If we understand physical reality, we will love our planet more. Understanding implies

evidence-based thinking; thinking like a scientist, as in Modeling Instruction, ISLE, and PUM. Then intelligent actions can follow. So we need **physics for all** in this crucial time in civilization!

Singapore seems to be aware of this. Physics is taken by most high school students; and teachers are expected to take 60 to 90 hours of PD every year, according to Singapore teachers who've been sent by their Ministry of Education to take ASU Modeling Workshops. So they know about the need for deliberate practice.

I have 3 practical suggestions for the U.S. Department of Education to restore funding for PD that is deliberate practice – i.e., meaningful effective disciplinary PD:
1) Make it affordable and attractive! Return to the central ideas of the Eisenhower program: a set-aside in state formula grants for Title II-A, focus on science, focus on deep content with effective pedagogy, open to all socio-economic strata; free tuition and/or stipends.
2) Require small grants: HUGE grants are counterproductive. They benefit few teachers relative to the wasted money on administration and external evaluation. Grants are risky and short-term, making it hard to hire personnel. Better to spread the money farther by having $50,000 to $100,000 grants. This would enhance the volunteer, local aspects: physics and chemistry faculty are willing to volunteer to organize a summer 3-week workshop for 20 teachers.
3) Prioritize high school physics and chemistry, the two core sciences that interface most closely with college and technical post-secondary trade schools, and thus get most commitment from post-secondary faculty to organize summer workshops. Physics and chemistry have the worst chronic shortages nationwide; e.g., ¾ of physics teachers in Arizona earned their degree in some other subject. Arizona produces 8 physics teachers per year, ~15 chemistry teachers, and 65 to 80 biology teachers, each year. The Eisenhower math and science PD program targeted out-of-field teachers, and that is still a central need. (See Appendix I. References are at http://modeling.asu.edu/AZ/PhysicsEnroll-NeedDouble.htm) ***

Legislation for teacher PD is quite simple: a few short paragraphs. Politicians' staff experts can write the legislation, but advocating for it is a task for physics leaders like Eric Mazur, who have connections in Washington, DC, and for organizations like the AMTA and AAPT, and networks like PoLS-T Network. This is policy, not politics.

I've tried to show here what IS possible. We must do something, and restoring the Title II-A set-aside for higher education seems the EASIEST way to increase local PD in physics. Of course, it should be on a higher turn of the spiral – requiring research-validated strategies like Modeling Instruction and Eugenia Etkina's ISLE – ideally, both together, in continuous improvement.

Modeling Instruction is described at http://modeling.asu.edu. Weblinks to ISLE and PUM are at 'weblinks for modelers' there (and many weblinks to high-quality resources).

END NOTES:

* Some of us faculty cooperated: In physics, in 1998 I convinced a physics professor at Northern AZ University and also at the University of Arizona to submit nearly identical proposals. All 3 of us got $50,000 grants; thus we provided 4-week summer physics Modeling Workshops for ~70 teachers, over 2 summers. That was 1/3 of the physics teachers in Arizona. It made a huge positive difference in the quality and quantity of physics, for several years. But it doesn't last; teachers retire. The economic recession in 2008 did terrible financial damage to schools. Many Arizona schools dropped physics since then, when their physics teacher retired.

**They were at 2 universities in Ohio, 2 in Maine, 2 in Wisconsin, 2 in Virginia, 2 in Missouri. Also New York, Massachusetts, Iowa, Hawaii, Pennsylvania, South Dakota, California, Florida, Indiana, Iowa, Arkansas, Michigan, Tennessee.

*** An endeavor by the National Academy of Science lends credence to these practical suggestions. In 2005, in order to think about the future economy, they convened a K-12 Education Focus Group. That group's top 3 recommendations for STEM teacher PD were (1) in-depth content and pedagogical knowledge; (2) scholarships for summer institutes and content-intensive degree programs; and (3) seed grants to universities for these two types of teacher PD. (No recommendation was implemented, sadly.)
Ref. http://www.nap.edu/catalog/11463.html (Appendix C) or
http://modeling.asu.edu/modeling/GathrngStormAppenC_K12.htm

APPENDICES:

APPENDIX I. Eisenhower Professional Development Program, Request for Proposals (July 2001) Arizona Board of Regents.

I quote from the introduction:

The purpose of the Eisenhower Professional Development Program is in part to strengthen the economic competitiveness and national security of the United States by improving the skills of teachers and the quality of instruction in mathematics and science, and other core subjects in the nation's public and private elementary and secondary schools through assistance to state educational agencies (SEAs), local educational agencies (LEAs – usually school districts), and institutions of higher education (IHEs).

The State Agency for Higher Education (SAHE) shall make funds available on a competitive basis to institutions of higher education in the state which apply for payments under this section and which demonstrate the involvement of local educational agencies. The State Agency for Higher Education shall make every effort to ensure equitable participation of private and public institutions of higher education.

The amount available shall be used for:
a. establishing preservice programs to prepare new teachers who will teach mathematics and science, and other core subjects;

b. retraining of secondary school teachers who specialize in disciplines other than the teaching of mathematics or science, including the provision of stipends for participation in institutes …; and
c. inservice training for elementary, secondary, and vocational school teachers and training for other appropriate school personnel to improve their teaching skills in the fields of mathematics and science, including stipends for participation in institutes …

Each institution of higher education receiving a grant under the subsection *shall assure that programs of training, retraining, and in-service training will take into account the need for greater access to and participation in mathematics and science careers by students from historically underrepresented and/or underserved groups, including females, minorities, individuals with limited English proficiency, the handicapped, and the gifted and talented, and will ensure cooperative agreements or cooperative arrangements with local educational agencies.*

(I have a pdf. It is no longer on the ABOR website. Reply to me if you want it. I cannot find the legislation on the U.S. Department of Education website.)

APPENDIX II. Excerpts from Title II-A section of "No Child Left Behind".

[For background and to show how easy it would be to start again. Copied/pasted on June 6, 2010 at http://www2.ed.gov/policy/elsec/leg/esea02/pg19.html and on following webpages. Important sentences are in red. In June 2021, I can no longer find it on the U.S. Department of Education website. Email jane.jackson@asu.edu for it.]

Improving Teacher Quality State Grants (etc.)

APPENDIX III: a quote by David Hestenes

"Lifelong professional development is as essential for science teachers as it is for doctors. Typically, it takes at least 10 years of deliberate practice to reach a high level of expertise in any profession. Few teachers have adequate opportunities for sustained professional development, and many have an inadequate background in science to start with, so most remain far from reaching their full potential as teachers. ... teachers need access to lifelong professional development like that provided by the AMTA in Modeling Workshops."

-- David Hestenes, ASU Emeritus Professor of Physics & co-founder of Modeling Instruction