

HIGH SCHOOL PHYSICS IN ARIZONA:

An update on low physics enrollment and shortage of physics teachers.

34 public high schools no longer have physics; 25 scholarships awarded to re-train in physics.

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Josh, my plumber, age 28, went to a public high school in Greater Phoenix. He regrets that he didn't take physics. *"It scared me"*, he said. *"I took earth science. I wish I had taken physics, because it's very practical knowledge that we use every day, whereas earth science is not practical."*

"Being 10 years out, I feel that physics has a very practical daily use. I clean drains; drains have to be sloped and use gravity. That's physics."

"To learn physics, you must have someone guiding you, explaining it. But earth science you can learn on your own. Don't get me wrong; I had a great earth science teacher. Earth science was easier, but it doesn't make my life easier now."

If Josh were in high school now, he might not even be able to take physics. Fourteen of the 100 comprehensive public district high schools in Greater Phoenix no longer have a physics teacher.ⁱ (See the map on page 5.) Physics is STEM: more than any other course, it combines science, technology, engineering, and math. High school physics is the chief STEM pathway to careers and college, research shows.ⁱⁱ It is crucial for health careers. Yet *only 20% of Arizona high school students take physics*. This is half the nationwide average of almost 40%.ⁱⁱⁱ

We are woefully underpreparing students by not giving them the one class – physics - that is a pre-requisite for nearly every STEM job. In Arizona, your zip code dictates your access to the level of STEM education you can get. Colleges want incoming students to have biology, chemistry, and **physics**. We must bring equity to students, and give **all** students opportunities and encouragement to take physics, no matter what their zip code.^{iv}

Furthermore, we jeopardize Arizona's economic future by not prioritizing high school physics. The STEM economy is here: half of new jobs in the 21st century will require skills that only 20% of the current workforce have. No one has realized that these 20 percenters are the ones with physics skills. Businessmen and politicians have failed to realize that physics is STEM!

The newly proposed Arizona science standards for high school will help; they put *physical* sciences on equal footing with *life* sciences (which until now have dominated). The standards advocate what should be taught. The next step is: how do we prepare teachers to implement the physical sciences standards? An even more basic question is: How do we get qualified teachers?

The teacher shortage in Arizona is in crisis, due to low salaries and costly health/dental benefits. As a highly-regarded school district administrator put it, "The Arizona legislature is starving public schools." Arizona teachers' salaries are lowest in the nation.^v

The problem is most severe in physics, and the problem is worsening as the STEM economy grows and private-sector salaries in STEM increase, while Arizona teachers' salaries are stagnant^{vi} – thus causing physics and chemistry teachers to leave the profession and go into more lucrative careers. Although about 300 teachers in Arizona teach some physics, *only 160 are left, who are certified in physics.*^{vii} And Arizona's universities prepare only 8 physics teachers each year (but 7 times as many biology teachers)!^{viii}

Low enrollment in physics in Arizona:

Physics is the canary in the coal mine! Thirty-four high schools no longer have physics, of 185 comprehensive public district high schools in Arizona. That's almost 20%. This is worse than two years ago. It is likely to worsen further.

Almost all Arizona public high schools still have chemistry.^{ix} Yet physics is more important than chemistry, for most STEM careers.

I separated the state into three regions: Greater Phoenix (within commuting distance of ASU-Tempe), Tucson, and rural Arizona (including Yuma, Flagstaff, and Prescott). Greater Phoenix has about 2/3 of Arizona's population, and Tucson and rural Arizona each have about 1/6.

Eleven of the 14 high schools in Greater Phoenix that no longer have a physics teacher are large, with 1000 to 2400 students. Low physics enrollment is primarily a school-level phenomenon, but it is influenced by district-level policies.^x

In rural Arizona, one-quarter (19 out of 62) of high schools eliminated physics after the 2008 recession. I include only schools that have 120 or more students. Typical enrollments are 300 to 800 students.^{xi} But some tiny rural high schools do offer physics -- every other year, alternating with chemistry, as Julia Slucas does at Salome HS (102 students). Salome is a migrant worker town in southwest Arizona. Julia's degree is biology; she re-trained in summers at ASU Modeling Instruction Program.^{xii} Tiny rural schools can have high physics enrollment!

Tucson is doing the best in the state: of its 22 comprehensive public high schools, only Santa Rita HS (410 students) lacks a physics teacher.

The low physics enrollment is due to too-low teacher salaries (and expensive medical/dental benefits), too-low school budgets, ignorance that physics is the most important science course for college and career readiness, and fear of math in physics.

Physics is crucial for economic prosperity!

Physics is the foundation of all sciences, technology, and engineering. It is the cornerstone of STEM. It deals with the simplest systems, and hence can use the most math. It helps kids with math. It is everywhere. It reveals how the world works. It unlocks mysteries of the universe -- yet is intensely practical, giving our kids skills that they can use no matter what career they pursue.

STEM fields are growing twice as fast as other fields. High school physics is needed for almost all STEM professions. A student who takes interactive engagement (hands-on, minds-on) high

school physics, such as Modeling Instruction, is three times more likely to earn a STEM degree than a student whose last high school science course was chemistry. (For evidence, see <http://modeling.asu.edu/modeling/STEMpathways-PhysicsAZ.htm>).

Physics is essential for college and career readiness for all. It contributes to scientific & math literacy. Thus regular/core physics is needed – not just honors, AP, and dual enrollment.^{xiii} Plumbers and HVAC technicians use physics daily^{xiv}; ALL communities need these vocations, no matter how remote. Likewise, they need medical/dental techs and other health workers.^{xv}

In short, the future prosperity of Arizona depends on a **strong K-12 education that includes robust physics courses. Arizona is failing badly!**

Our policy work to double physics enrollment by increasing the number of physics teachers: Mike Vargas, a physics teacher in Phoenix, was runner-up for Arizona Teacher of the Year in 2015-16. He initiated a statewide policy endeavor in summer 2016. He and I, joined by a small dedicated band of physics teachers who want to make a difference, convinced the Arizona legislature to pass SB1038 in 2017. It appropriates \$300,000 for 150 scholarships of \$2000 each, for K-12 teachers for professional development to ADD a certification or credential in STEM or CTE.^{xvi} Details: <http://azk12.org/homeroom/2017/08/24/teacher-leadership-in-action-mike-vargas>

By mid-March 2018, all 150 scholarships were awarded: **25 to re-train in physics** (and 7 to prepare to qualify for physics dual enrollment). **In chemistry, 12 to re-train** (and 6 to prepare for dual enrollment).^{xvii} Not nearly enough! These scholarships are just a start, to solve the problem; only 3 scholarship awardees teach in the 34 high schools that lack physics. (Two teach in Sierra Vista HS in Tolleson UHSD and one in Valley HS in Sanders.)

Much more work is needed. High school principals and guidance counselors must be convinced to prioritize physics. And we must take this pilot program to the next level, as a permanent broad-spectrum solution to getting high-quality teachers to our students.

Related work

A. Surveying guidance counselors and students: why low physics enrollment.

In fall 2016, I got a \$10,000 grant from the Boeing Company in Mesa AZ for Larry Dukerich and Earl Barrett, retired physics teachers in Mesa, to investigate causes of low physics enrollment. They surveyed 75 Arizona high school counselors and 875 chemistry students, with help from Kay Schreiber at the Arizona Department of Education (ADE). They found that *“The majority of counselors believe, erroneously, that physics requires a student to have exceptional math skills and a desire to be an engineer. Without a belief that physics is important for anyone interested in a STEM career, they often steer students to other science courses. The school seems to have no big picture that recognizes that a vibrant physics program better prepares students for a STEM career than does AP coursework.... The AP model does not work for the majority of our students.”* Students in high school chemistry have similar erroneous beliefs.^{xviii}

B. One-day workshops at ASU for teachers, on how to increase their physics enrollment.

In spring 2016 and in fall 2017, I won \$1000 AAPT Bauder Fund grants for workshops on physics projects and demonstrations. They were held at ASU and led by local physics teachers Melissa Girmscheid, Zachary Kovach, and Theresa Burch. Two dozen teachers participated in each workshop. A teacher, new to physics, implemented the ideas and increased his enrollment from 1 section now to 5 sections next year. See <http://increasephysics.weebly.com/workshop-info.html>

ASU professional development in STEM for teachers:

ASU Modeling Instruction is the chief professional development provider for almost all of the \$2000 scholarship awardees in physics and chemistry. A \$2000 scholarship can pay for FIVE non-credit ASU Modeling Workshops (@ \$400 each), or one summer Modeling Workshop for ASU graduate credit. Dorm housing is pleasant; low-cost family housing is available; and Title II funds are an ideal use for housing. *Schools and districts need to value physics enough to allocate Title II funds; that is a challenge (and the Trump administration proposes eliminating Title II).*

Each summer, 80 teachers come to ASU for 3 weeks to take intensive (90 contact hour) Modeling Workshops. We have 10 distinct Modeling Workshops: 5 in physics, 3 in chemistry, and 2 in physical science. Courses are coherent, since they are organized around a small number of scientific models. Courses are content-intensive; and integration of physics, chemistry, and math is emphasized. Modeling Instruction is interactive engagement and of proven effectiveness. The ultimate target is not the teachers themselves but their students. Therefore each course addresses the subject at a level that prepares them to entice and inform their students.^{xix}

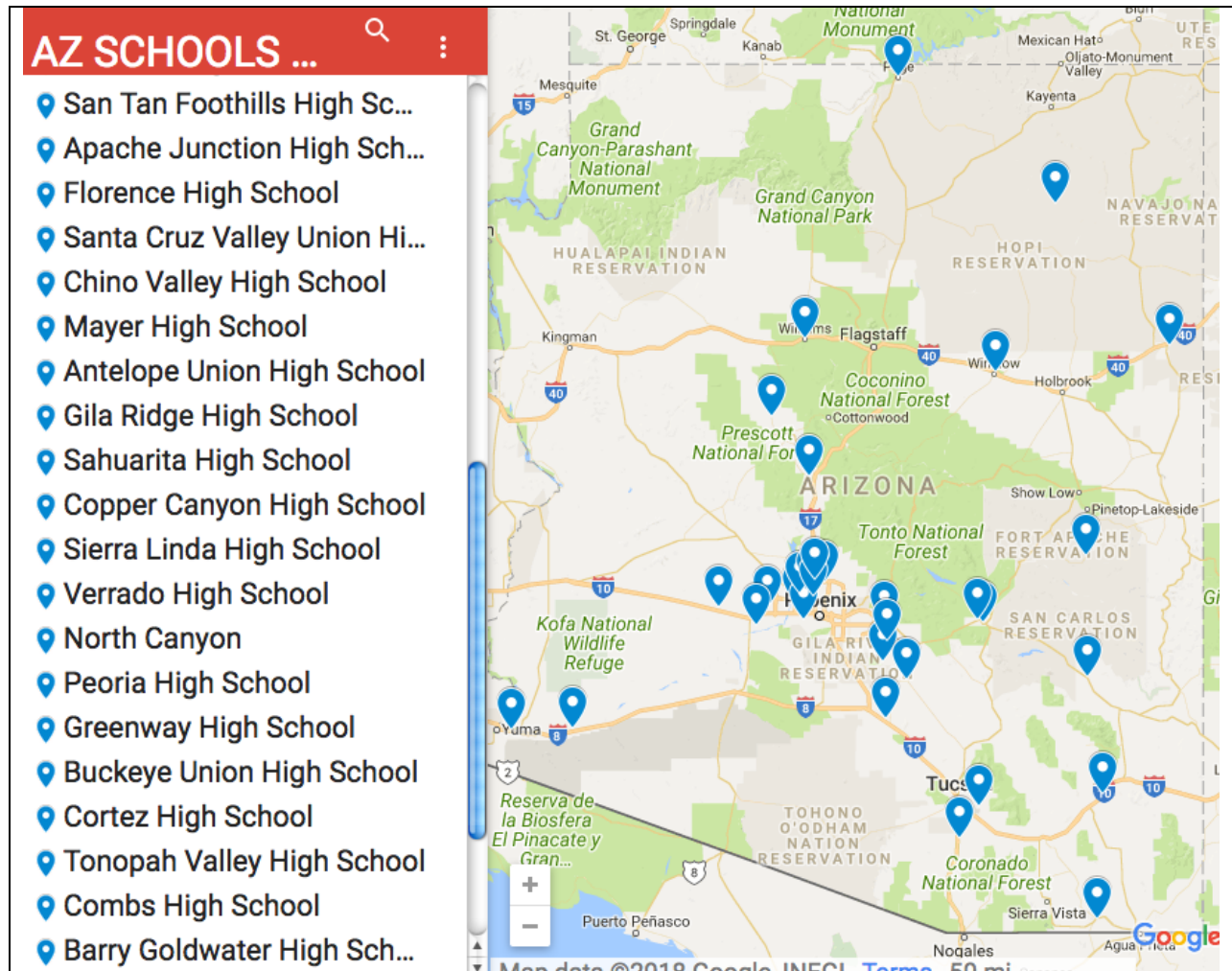
Overwhelmingly, teachers wrote that ASU Modeling Workshops are the BEST preparation to pass the Arizona physics certification test! We have helped many teachers prepare to qualify to teach dual enrollment, too: most earned the MNS summers-only degree in physics at ASU. (For evidences, see <http://modeling.asu.edu/MNS/MNS.html> .)

Future policy work is needed: Mike Vargas and I made a good start, but MUCH more work needs to be done. High school principals need to be convinced that physics is crucial for 21st century STEM jobs -- vital for college and career readiness! So do guidance counselors, as Melissa Girmscheid can attest from her personal experience with her daughter, who was counseled AWAY from physics, even though she wants a medical/health career.^{xx}

References and resources:

These resources are available at <http://modeling.asu.edu> at the bottom of that webpage.

- * The AZ high schools that no longer have a physics teacher are listed in a 7-page document.
- * A 1-page document by Mike Vargas and me (with help from Larry Dukerich and Earl Barrett).
- * Why AZ physics enrollment needs to double (2 pages, with research quotes showing that physics is the chief STEM pathway to college and careers).
- * Open letters to high school principals and the business community, by Larry Dukerich and Earl Barrett, based on their 2017 surveys of AZ guidance counselors and chemistry students.
- * Detailed plans by Earl Barrett and Larry Dukerich, for how teachers and principals can transform a high school physics classroom to hands-on, minds-on interactive engagement.



Some of the 34 public high schools in Arizona that no longer have a physics teacher.

Endnotes

ⁱ In 2015, nine high schools lacked a physics teacher, so the problem has worsened in 2 years. The 14 high schools in Greater Phoenix that no longer have physics (via a resident physics teacher) are, in order of size: Copper Canyon HS (almost 2400 students!), North Canyon HS, Barry Goldwater HS, Sierra Linda HS, Verrado HS, Peoria HS, Buckeye Union HS, Greenway HS, J O Combs HS, Apache Junction HS, Cortez HS, Florence HS, Tonopah Valley HS, San Tan Foothills HS (400 students). A physics teacher travels to Peoria HS and Verrado HS for one period/day; a stopgap measure. Each of those 2 schools should have a full-time physics teacher.

ⁱⁱ The ACT policy platform: K-12 (2013) states (page 8): "ACT research has demonstrated the benefits to student academic performance of a minimum core curriculum that includes the following: ... Three years of science, including rigorous courses in Biology, Chemistry, and **Physics** ... "

Specifically:

* "Students who take the ACT-recommended core curriculum in high school achieve higher ACT scores than those who do not. Compared to graduates who do not take the core curriculum, graduates who take the core curriculum earn composite ACT scores that are, on average, three points higher." ...

* "Compared to high school graduates who do not take the recommended core curriculum, graduates who take the core are more likely to be ready for workforce training programs."

<http://www.act.org/content/dam/act/unsecured/documents/Policy-Platforms-k-12-online.pdf>

"We find that the number of years of a science or math subject taken in high school is associated with significant increases in STEM career interest, with results differing by subject. Taking AP courses in science or calculus appear to have no significant impact on STEM career interest over that of other advanced, non-AP courses. Taking calculus, a second year of chemistry, or **one or two years of physics** all predict large increases in STEM career interest. Additional years in biology and other subjects show no such relationship." Philip M. Sadler et al. (2014). *Science Educator*, Vol.23, No.1, pp. 1-13. See Fig. 3.

http://nsela.org/images/stories/scienceeducator/Summer2014/Sadler_231.pdf

"... students in the highest levels (**Physics I** and Chemistry II or Physics II) are significantly more likely than students in the Chemistry I only group to obtain a baccalaureate degree in a STEM major. ... This finding may also suggest that **Physics I**, Physics I with Honors, AP Physics B, or AP Physics C are higher level courses than comparable Chemistry I courses ..."

Will Tyson et al., (2007). *Science, Technology, Engineering, and Mathematics (STEM) Pathways: High School Science and Math Coursework and Postsecondary Degree Attainment*, *Journal of Education for Students Placed at Risk*, Vol. 12, No. 3, pp. 243-270.

Research by others is cited at <http://modeling.asu.edu/AZ/PhysicsEnroll-NeedDouble.htm>

ⁱⁱⁱ American Institute of Physics data on high school physics enrollments and availability in USA:
<https://www.aip.org/statistics/reports/high-school-physics-courses-enrollments-0>
<https://www.aip.org/statistics/reports/high-school-physics-availability-0>

^{iv} ACT report (March 2018): *STEM Education in the U.S.: Where We Are and What We Can Do*.
<https://www.act.org/content/act/en/research/stem-education-in-the-us-2017.html>

"ACT research has shown that taking rigorous science courses, including physics, in high school is vital to college readiness ... however, in 2015, fewer than 50 percent of high-poverty high schools offered any physics courses" ... See *Rigor at Risk: Reaffirming Quality in the High School Core Curriculum* (Iowa City: ACT, 2007). In pdf at <https://eric.ed.gov/?id=ED496670> [See pages 28 and 30.]

^v The Arizona Republic cites a recent study, in an article on March 8, 2018, at <https://www.azcentral.com/story/news/local/arizona-education/2018/03/08/arizona-public-school-teachers-elementary-high-school-paid-compared-other-states/407850002/> . I quote: “The most recent — and arguably most equitable — comparison of teacher salaries nationwide is a May 2017 analysis by Arizona State University's Morrison Institute for Public Policy. That analysis adjusted the numbers to take into account the cost of living in each state.

According to that data, the median salary for Arizona elementary school teachers in 2016, adjusted for regional purchasing power, was \$42,474. The median salary for high school teachers was \$47,890.

When all state salaries are adjusted in this way, Arizona ranks 50th in the nation for elementary teacher salaries, and 49th for high school teacher salaries. Oklahoma ranked 50th for high school teachers.”

^{vi} Many teachers’ salaries are under \$40,000, and they are paying student loans. Salaries were frozen for up to 8 years. Most physics teachers are men. Many teachers have young children; some are single parents. Some are putting children through college. A family of 4 needs an income of twice the official annual poverty threshold of \$24,000 to cover basic expenses: housing, food, transportation, health care, and child care. That is \$48,000 per year. [Ref. The Annie E. Casey Foundation (2014): Creating opportunity for families: A two-generation approach. Baltimore. <http://www.aecf.org>]

^{vii} The Arizona Department of Education (ADE) research division reported to Mike Vargas that 159 certified physics teachers taught physics in 2015-2016; 9 fewer than the previous year. My data reveal that about three-fourths of Arizona physics teachers did not major in physics nor in physics education. Also, my data suggest that only 1/3 of Greater Phoenix physics teachers are fully utilized; i.e, teach physics full-time -- most teach only one or two sections.

^{viii} You can find the number of AZ students who passed the PHYSICS or CHEMISTRY TEACHING CERTIFICATION test at <https://title2.ed.gov/Public/Home.aspx#> These numbers of people passed the AZ teacher certification tests in physics, chemistry, or biology.

AZ totals:	physics	chem	biology
2015:	9	15	62
2014:	8	17	72
2013:	8	17	75
2012:	7	7	88

Trends:

- * 7 times more new biology-certified teachers, than new physics-certified teachers. Imbalance!
- * The number of new biology-certified teachers is declining.
- * All 3 state universities have steady production of new physics-certified teachers (but in 2016 there were 25 open positions in PHYSICS in Greater Phoenix: 3 times as many openings as qualified applicants in ALL of Arizona).

^{ix} Tuba City HS (700 students), Thatcher HS (450 students), and Pinon HS (360 students) no longer have a chemistry teacher. Santa Rita HS in Tucson (410 students) has a long-term sub.

^x In Glendale Union High School District, which prioritizes Advanced Placement courses, 2 of its 9 large high schools do not offer physics, 6 high schools have less than 5% of students taking physics, and 1 high school (Sunnyslope) has *5 over-full sections* (taught by a committed young teacher who is earning an ASU MNS degree).

In Tolleson Union High School District, a high-poverty district, 2 of its 4 comprehensive high schools (Copper Canyon and Sierra Linda) have NO physics, and La Joya HS has *13 sections of physics*. (The lead teacher is Zachary Kovach, a young 2nd career teacher who leads ASU summer Modeling Workshops. Zak was PhysTEC Teacher of the Year in Phoenix in 2016.)

This hit or miss situation must be rectified, and low/no enrollment drastically increased. Exemplars like these two can help, if awareness and public pressure exist.

^{xi} The 19 rural high schools are, from largest to smallest: Gila Ridge HS (in Yuma: 2000 students), Sahuarita HS, Page HS, Chino Valley HS, Winslow HS, Tuba City HS, Alcheyay HS, Globe HS, Thatcher HS, Santa Cruz Valley HS, Willcox HS, Pinon HS, Bisbee HS, Miami HS, Williams HS, Valley HS (in Sanders), San Manual HS, Mayer HS, Ft. Thomas HS (120 students). (Joseph City HS, Superior HS, and 8 other high schools with fewer than 120 students are not counted. The 6 Bureau of Indian Education high schools are not counted, since they are funded differently; 4 of them no longer have a physics teacher since the 2008 recession.)

^{xii} Another rural example is Betty Hultin, a retiree who is back in the classroom, teaching physics this year at Seligman HS (~50 students in the entire high school) in northwest Arizona. She took two summer Modeling Workshops in physics, 20 years ago, to re-train. A third example: Physics is taught every year at Valley Union HS in Elfrida (~125 students) in southeast Arizona. A fourth example: Every ninth grader at Morenci High School takes physics. Morenci is a mining town; the high school has almost 100 9th graders and a full-time physics teacher.

^{xiii} Physics has become an elitist course in Greater Phoenix, unfortunately. In 1998, 70% of physics courses in Greater Phoenix were regular/core, and 30% were honors or AP; this was similar to national averages. But by 2015, the course level in Greater Phoenix was reversed: *only 30% of physics courses were regular/core, and 70% were honors/AP/DualEnrollment*. (In contrast, nationwide now, about 35% of physics courses are honors/AP/second year.)

^{xiv} I interviewed a HVAC-refrigeration service technician, age 30, in May 2017. Xavier went to a public high school in Tempe. He didn't take physics, but he wishes that he had. He began a 2nd career as HVAC technician in 2016, and for that he was completing a 9-month training at refrigeration school. He said, "*The first month was understanding switches -- how electrons flow: open, closed, grounded. Electrons flow like water flows in a water hose. I paid \$17,000 to learn this; I could have learned it for FREE in high school. High school physics would be such a great start! It is crucial for MY career. Everything in a/c is change of state.*"

“ I believe that high school physics is crucial for any profession that my 9-year old daughter would go into. She will go to my high school, too. I want her to take physics. We want the best for our kids.”

^{xv} A university physics professor in Phoenix wrote the following listserv post in October 2018.

“Students with a desire to go into a health career (medical doctor, dentist, pharmacist, P.A., P.T., etc.) seem to have no idea that College Physics (PHY-111 and PHY-112) will be required courses for their undergraduate degree – and neither do their high school guidance counselors (and perhaps neither their science teachers).”

*“ Every year I teach College Physics to 200+ pre-health students, of which only about 1/3 took physics in high school. When asked why they did not take physics, the typical answer is that **they did not know it was going to be important**. Occasionally I will have a student tell me that it was not offered at his/her high school, but far more common is that it was offered, but **they chose - or were directed - to take life science classes** (e.g. AP Biology, Anatomy and Physiology), since that was going to be “their field”.”*

“Not only is Physics a requirement for most health care graduate programs and subsequently usually a requirement for the chosen undergraduate program (e.g. BS in Biology), it is also included on many of the graduate school admission tests (e.g. MCAT, Dental Admission Test, Optometry Admission Test). With the College Physics courses ideally covering all the topics on those graduate school admission tests, the courses end up packed with content and the pace is generally quite fast. Every semester I have countless students telling me how they now regret not having taken physics in high school, and other students telling me how glad they are that they did take physics.”

“Nationwide physics, along with organic chemistry, take the top ‘honors’ for being the courses that stop the most students from getting into medical careers because of the low scores (or even difficulty passing at all). Not exactly an ‘honor’ to be proud of. And largely preventable if the students came to college with a background of high school physics.”

^{xvi} Most of our work was in summer 2016; Mike and I met with six legislative leaders in their offices. That summer and that fall, Mike did much emailing to legislative leaders, to keep them focused on the issue. Their education policy director, a former biology teacher, worked up a bill: The High Quality Teacher Professional Development Pilot Program. In winter 2017, we had to testify at committee hearings, which meant that Mike had to take personal leave a few times. Jeff Hengesbach, Melissa Girmscheid, Larry Dukerich, and Earl Barrett testified, too. I did a lot of work on it in spring 2017, calling and e-mailing 50 or so physics and chemistry teachers in the entire state, asking them to contact their AZ legislators and vote YES. Mike’s and my skills complemented each other. Working together, we succeeded!

^{xvii} Since August 2017, I have spent much time making teachers aware of the scholarships, personally and via our listserv for Arizona physics & chem teachers/faculty (1000 subscribers). Teachers have no time, and they need much encouragement to pursue re-training.

Of the 34 schools that lack a physics teacher, only 2 got scholarship awardees in physics. I am disappointed, because I repeatedly emailed and phoned principals and counselors of most of these schools; only 3 principals responded. Only Sierra Vista HS in Tolleson (1650 students)

convinced out-of-field teachers to apply for \$2000 scholarships. Also, the ADE sent many e-mails to 65,000 school administrators and counselors, from July 2017 to March 2018. Why didn't the other 30 high schools act on our efforts? An ADE employee (a former principal), offered this insight: that "*schools are resource-poor and are taking one step at a time, trying to keep their head above water.*" Financially-starved public high schools need resources.

^{xviii} Larry and Earl wrote up their survey results in open letters to principals and businesses (download in pdf at <http://modeling.asu.edu> at the bottom of the webpage). In fall 2017, they submitted a 1-hour convention workshop proposal to the Arizona School Counselors Association, but they never heard back.

^{xix} Modeling Instruction was developed in the 1980's by Malcolm Wells, a veteran physics teacher at Marcos De Niza High School in Tempe, in collaboration with his doctoral advisor, ASU physics professor David Hestenes. It corrects weaknesses of the traditional lecture-demonstration method, including fragmentation of knowledge, student passivity, and persistence of naive beliefs about the physical world. Modeling Instruction is designated by the U.S. Dept of Education as an Exemplary K-12 Science and a Promising K-12 Technology program. It received the 2014 Excellence in Physics Education Award of the *American Physical Society*.

^{xx} Prospective partners and allies.

* Four staff at the AZ Department of Education with whom we are working: (Kay Schreiber with counselors; Steve Larson and Keith Snyder with Title II, Alexis Susdorf in marketing).

* Jeremy Babendure founded *Chief Science Officers*, elected student body officials in hundreds of AZ middle and high schools. They will be appalled when they learn that they cannot take physics, and they will demand qualified physics teachers. The CSO initiative is described at <http://stemecosystems.org/ecosystem/arizona-scitech-ecosystem/>

*The Arizona Technology Council and other STEM-based industries will contribute when they learn about the dearth of high school physics. But we lack time and personal connections to make STEM companies aware of low physics enrollment.

* Larry Dukerich and Earl Barrett met with a key staff at a Phoenix foundation, and with a leader at Greater Phoenix Leadership. They have tried hard, but it takes repeated efforts over time.