Challenges of Preparing Physics Teachers in the United States

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Abstract

The United States, like much of the world, does not have enough qualified physics teachers. As in Germany the educational system in the U.S. varies greatly from state to state. Thus, efforts to improve the number and quality of physics teachers vary throughout the country. However, some efforts are national in scope. The Physics Teacher Education Coalition, PhysTEC, focuses on common goals in preparing teachers of physics at all levels. Another project, Physics Teaching Web Advisory (Pathway), emphasizes support for teachers who are already teaching physics but have less than adequate preparation in physics or the pedagogy of physics. Pathway is a new type of digital library for providing ongoing enhancement and preparation for physics teachers and combines state-of-the-art digital video library technology with contemporary ideas about pedagogy and materials contributed by teachers. Carnegie Mellon University's "synthetic interview" technology provides the foundation for a system that allows physics teachers to ask questions of a virtual mentor and get video responses. Through an analysis of the questions asked in the system we have obtained a rich database of information about just what types of support teachers of physics in the US are requesting. This information and other efforts are helping us design support systems for physics teachers, both new and experienced.

1 Introduction

Figure 1, a graph produced by the American Institute of Physics, contains some good news. It shows the enrollment in high school physics in the United States from 1930 to 2005. The vertical axis is the number of students finishing a physics course as a percentage of the total number of students graduating from high school in each year. This percentage has risen. It dropped in the mid-1970s, but it has risen since then, and it seems to be on an upward path now. That is good news in terms of what is happening with the study of physics in the schools. In 2005 slightly more than 1.1 million students were taking physics in the schools.

(A slight linguistics digression: In Germany we use Schuler and Schülerin for people who are studying in schools while Student and Studentin are reserved university students. Likewise, the British make the distinction between pupils for people in primary and secondary schools and students for the university. In the U.S. make no such distinctions. So, the word "students" can refer to people who are being educated at any level or age. Here, when I talk about students, I am referring to high school students who are about 15-18 years old.)

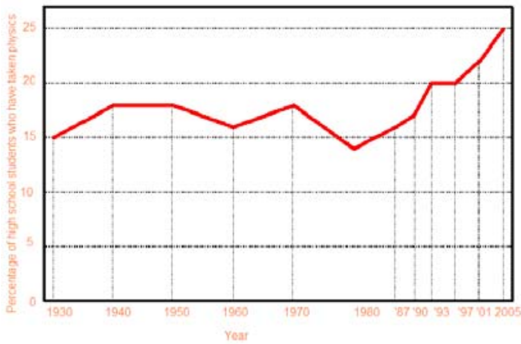

Figure 1: The enrollment in high school physics in the United States as a percentage of total high school enrolment, 1930-2005. (Source: American Institute of Physics)

2 Educational System in the United States

First, I need to provide a little background on the American educational system. Of course, one could spend a full hour just discussing some of the differences the U.S. and the German educational systems. However, this discussion will be limited to just a few key elements.

From a distance the United States may look like one large uniform operation. However, in terms of educational systems, it is somewhat like Germany. Each of the 50 states has its own way of deciding what is taught and how it is taught the secondary schools and the primary schools. To a lesser extend the states can also decide what happens in the universities.

At smaller units than the state level, the United States citizens have a strong believe in local control of schools which starts at the state level and works its way down to individual communities or, in some locations, parts of communities. There are more than 13,000 individual school districts in the U.S. These districts fortunately do not have control over deciding who can be certified to teach at a particular level or a particular topic– that happens at the state level. But they do have control over what gets taught in many but not in all states.
Figure 2 is a map showing the school districts. It also shows how states differ in establishing these districts. For example, Hawaii has one district for the whole state; Nevada has a few districts which cover very large geographical regions; and Kansas has many small districts.

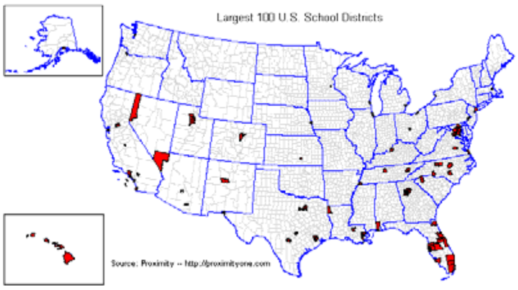

Figure 2: This map shows the individual school districts in the United States. The districts in red are the 100 largest ones. (Source: http://www.proximity.one.com

Financing of schools is quite different from Germany in that it is closely tied to those individual school districts. Taxes are collected on property. This arrangement means that a school district in which a large number of homes cost a million dollars will have a large amount of money for schools. If they have many of low-cost homes and few high-cost ones, they will have much less money. Not all of the money comes to the schools in this way, but the fraction is large. The result is that some schools are quite rich; some schools are quite poor. Of course, the amount of money available affects how one teaches all subjects and particularly laboratory subjects such as physics.

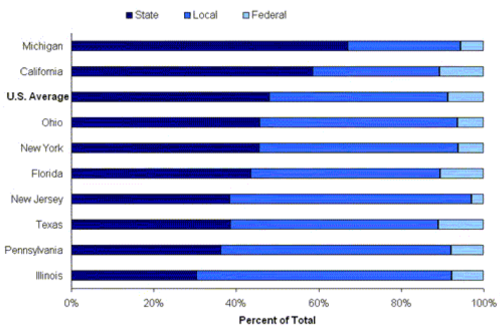

Figure 3: The fraction of the schools funding that comes from state, local and federal sources. (Source: the National Education Association)

Figure 3 provides a view of where school money comes from and how it differs by state. It shows the fraction coming from federal, state, and local sources. The fraction from the state will be relatively uniform across all schools in that state. The part that comes from local sources – individual school districts – will vary greatly with the wealth of the people in that district. A very small fraction comes from the federal government. However, that small fraction is important to schools, so the present administration in Washington can use a threat to cut off those funds if schools do not implement its "No Child Left Behind" policies.
How students move through the education system in the U.S. is also quite different from the German system. Figure 4, taken from Wikipedia, is at least one person's view of the different schools and opportunities in the German educational system.

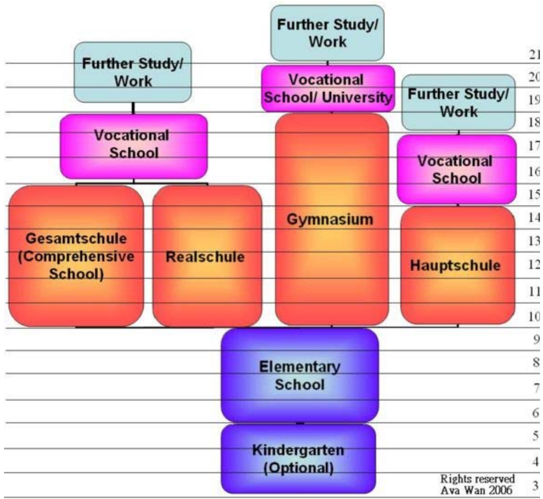

Figure 4: A graphical view of the German school system. (Source: http://wikipeida.org)

Wikipeida's view of the American system is much simpler. In fact it is overly simplified so a slight variation is shown in Figure 5. The most important point is that the U.S. has, for the most part, a general school system (Gesamtschule) operation. All students regardless of academic ability or career goals attend the same school from kindergarten, which is the first year of school, up to grade 12 and then people branch off in universities, community college, technical schools, or work.
Some exceptions do exist. We have private schools which require a certain academic standard (and a large amount of money) and magnet schools which focus on specific academic disciplines. However, most students in the U.S. will attend a general school from kindergarten through Grade 12
In the U.S. school grades are labeled in somewhat the same way that Germans label the different floors in a building. The first year of school is not Grade 1. It is called kindergarten – a nice German word that has a totally different meaning in American English. The final year in U.S. secondary school is Grade 12.

Figure 5: A view of the U.S. schooling system. (Modified from Wikipedia)

When you read about America's school system, you frequently see the term K-12. That refers to all of pre-university education – K (kindergarten) and then Grades 1through 12. In total it is really 13 years.
One of the biggest problems in the United States today is the students who leave school before finishing high school. Almost no career is open for them. Unfortunately a large fraction of these students are ethnic minorities and a large fraction of those are males. They usually stop their education in secondary school.

3 Educational Standards

A variety of educational standards, particularly in science, exist in the United States. Perhaps the most well known are National Science Education Standards [1] and the 2061 Benchmarks from the American Association Advancement of Science [2]. All of these standards are recommendations. They are not mandatory. However, almost all of the states have begun with these standards and created their own set of standards from them. The state standards may or may not be mandatory within the state. Frequently, they are recommendations to the schools but sometimes teachers are required to teach to them. In most states teachers are *expected* to teach to the standards and to show that their students are learning what the standards recommend.
To provide an idea of variation in States, Figure 6 indicates the number of required years of science for completing high school – the last four years of schooling – in each of the states. All 50 states are represented but only a subset of them labeled. They are in alphabetical order. The blanks indicate that the state itself does not have any rules; the state expects the local school district to make those rules.

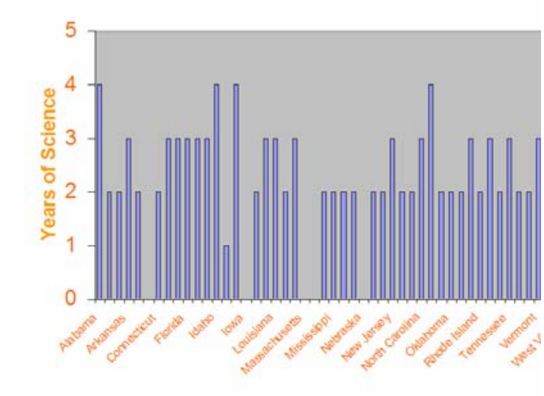

Figure 6: Number of years of science that is required in high school as a function of the state. (Data source: National Center for Educational Statistics)

It still expects that the students will complete science courses. For those states with state-wide requirements the range is from one year in Illinois up to four years in several states.

4 Teacher Certification

Teacher certification is established in almost all states by the state Department of Education, the equivalent of a Bundesland Ministry of Education. Some reciprocal agreements allow teachers who are certified to teach in one state to teach in some others. Other states would allow a teacher who is certified in one state to teach in their state only after taking a few. In other cases a state may not recognize certification from some other states. In all cases the state Department of Education is in control.

5 Physics in Secondary School

Unlike Germany, physics is taught in one year in the secondary school, mostly in the 11^{th} or 12^{th} grade. In the school year we have about 35-38 weeks of instruction in a school year. This number varies a little from state to state. However, most states have about 10-12 weeks of holiday in the summer and about 3 weeks holiday spread through the year.
Typically a class in a school is one hour per day, five days per week. Within that time the teacher will cover lab activities, lectures, problem solving, and other teaching-learning activities. Traditional physics topics are taught for the most part. Very little modern physics exists in most high school courses. Thus, the first semester is primarily mechanics with some thermodynamics and the second semester is primarily electricity and magnetism with some wave motion and/or optics. In many schools the teacher will have some freedom in selecting topics.
The mathematical level is primarily algebra with no calculus. Some schools offer a conceptual physics course with little mathematics, while some offer advanced, second year physics, which may be based on calculus.

Several years ago, some people including some well known physicists advocated "Physics First." The first science course in high school would be physics and would be taken by all 9th Grade students. That movement is not dead yet, but it is not very healthy at the moment. One of the primary issues is the lack of teachers prepared to teach physics to this very large group of students.

6 Who Teaches Physics

Figure 7, again from the American Institute of Physics, shows data that were collected about five years ago. It indicates how many university physics courses that school physics teachers have completed. As shown in the graph a small percentage has never had a physics course and yet they are teaching it. About 30% have had a large number of courses, the same number as a typical university physics student. Fro the other teachers, the number of courses varies across the spectrum. Importantly, a large number of teachers have not completed a university physics education but they are teaching physics.

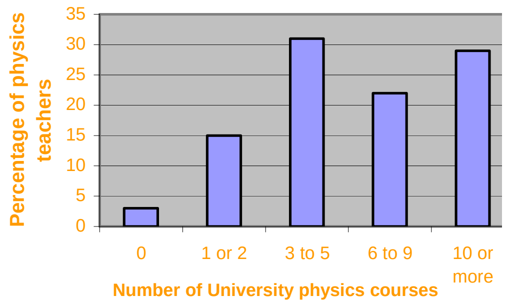

Figure 7: The number of university physics courses completed by teachers who are teaching physics in high school. (Source: American Institute of Physics)

In the U.S. 21,200 people were teaching physics as of a couple of years ago. Each year U.S. schools need about 1000 new physics teachers. About 300 of those new teachers will have completed 6 or more university physics courses – the top two categories of Figure 7.

Another issue is that teachers do not stay in the profession very long. They frequently spend 5-6 years at the University becoming qualified to be a teacher. Within five years they have decided not to teach. About ½ of the teachers in the schools disappear within 5-10 years after they have completed the education to become a teacher.

The problem is that teaching is not a very prestigious profession. Teachers keep hearing about how the schools are bad, and it is their fault. So, they can be happier in other professions. Unfortunately physics is one of the biggest problems. A large fraction of physics teachers disappear in part because they are mobile in term of careers. A person who has studied physics can find a job in a technical industry rather easily.

To provide concrete details on physics teacher education let us focus on the situation in Kansas. Our state has two or three moderately urban areas in it, one right on the border with Missouri (Kansas City), Topeka (which is the state capitol) and Wichita where many airplanes including 747s are built. The rest of the state is quite rural. Kansas has a population density that is a little different from many parts of the country, but its distribution of teachers is not much different.

First, we do have students who study physics at the university and complete extra courses to become teachers. They would fall in that top (far left) group on the histogram in Figure 7. Then, we have people who are generally studying science education and choose physics as their specialty. They take fewer physics courses than the first group, but still quite a large number. In both of these two groups students will complete enough courses to teach chemistry and probably mathematics. Finally, another group of future teachers are studying any other science or mathematics for their primary discipline. They are allowed to teach physics by completing three courses in physics.

One other group is also teaching physics. These teachers are already in school and may have little or no physics training. They receive "emergency certification." An emergency in the school is that it does not have a physics teacher. The school administration selects some existing teacher to teach physics. The Kansas Department of Education will issue an emergency certification that will allow the teacher to teach physics for about two years. During that time he/she must complete courses to reach the same level of physics knowledge as the future teachers who take three courses in physics. Usually just about this time of year we receive emails and phone calls, "Are you offering any courses for teachers during the summer? My biology teacher will be teaching physics next year. She or he has had one physics course but needs another one." Some summers we can fulfill the request; others we cannot.

In terms of numbers we have very few physics students (1 every 4-5 years) who have decided to become teachers and get the teaching certificate. A few more students choose science education with physics as a specialty (about 1 every 2 years). The number of future teachers of other sciences or math who take the three courses is quite a bit larger, about 4-6 a year.

We have no idea how many emergency certifications there are, but we know it is not a small number. All of these teachers are trying hard. Some of them become very good physics teachers.

7 A Course for Future Teachers of Physics

Our university has a special course for the students who take three physics courses in order to finish their certification in physics. It is important to emphasize that these students have many other science courses. If a student is studying to become an English teacher and takes three courses in physics, he or she cannot be certified to teach physics. But if the student will become a biology or chemistry teacher, the three courses are sufficient. The Kansas Department of Education requires two semesters of introductory physics which counts as two of those courses. This course can be algebra-based or calculus-based. Then, students must complete one additional course and that course must have a laboratory. The Department of Education allows the University to decide what course or courses are appropriate for that third course.

In our situation, the first two courses are typically the same courses that a medical student would take. The third course is something we created especially for our future teachers. Many years ago we just told the future teachers to take mechanics, our first course in quantum mechanics or something similar. However, these students were not as well prepared for these courses as the physics students. They would struggle. They would get very low grades but they would pass the course. So, we decided to create a course which allows them to learn physics that they could use in teaching and learn some things about modern pedagogy. Thereby we hope they would become better physics teachers.

As stated above we have only about 5 students per year. To have sufficient enrollment, we have opened this course to other interested students who would just like to take a contemporary physics course. We get about 20 students per year in this course of which five or six will be future teachers.

The issue of creating materials that does not involve a lot of study of physics in order to learn some quantum mechanics came from teaching this course. I was very unhappy with the topics that I was teaching, so we started working on different ways to teach quantum mechanics. That led to *Visual Quantum Mechanics.* [3, 4]

8 A national Effort – PhysTEC

While the states control the certification and standards, physics departments see some common issues that need to be addressed. One effort to collaborate throughout the country is the Physics Teacher Education Coalition (http://www.phystec.org/), commonly called PhysTEC. (You are hearing about PhysTEC from an outsider. I am not part of PhysTEC.). It is a joint effort by the three major physics organizations in the United States, American Institute of Physics, American Physical Society and the American Association of Physics Teachers. It has a rather broad mission, "To improve and promote the education of future physics and physical science teachers." PhysTEC is interested in improving the teaching of physics at all levels. Not just in the high school but throughout the school system.

They have established a network of institutions involved and interested in this mission. More specific goals include producing more and better prepared teachers, providing evidence that this effort really is valuable and, most importantly, trying to get physics departments more involved in understanding the problems of working with teachers, preparing better teachers and working with their colleagues in faculties of education to make the system work better. All of these goals are aimed at making physicists part of the solution to this very complex problem. Further, physicists need to realize that the solution is not just increasing the number of physics courses but creating a broad understanding of physics, pedagogy and the interaction of the two.

PhysTEC has two parallel streams. They have a national coalition that has conferences, that recognizes good programs and so forth. The other stream involves some demonstration projects which are looking at particular components and trying to make models that others can follow.

One particular idea is the teacher in residence. A high school physics teacher joins a university physics faculty for a year. He or she provides a link between the department and practicing teachers which hopefully improves relationships with the schools and maybe helps in recruiting more teachers. A physics teacher already has knowledge of the faculty of education so hopefully his or her presence improves the bridge between physics and education faculty. Further, this person is a part of the faculty of physics so he or she would be teaching courses just like every other professor. Finally, he or she talks to the physics professors and helps them improve their understanding of the issues related to teaching in schools.

The successes of PhysTEC so far include the conferences that have worked quite well. They also have a physics education digital library and are putting together a book of "Best Practices." The demonstration sites have doubled their production of physics teachers. Unfortunately, the numbers are still quite small, but it is a place to start.

Further, the program gets frequent publicity. Certainly, the involvement of the American Physical Society and the American Institute of Physics with the American Association of Physics Teachers is very important. Thus, physicists in a variety of physics areas are likely to pay more attention than they might otherwise.

9 Help for Existing Teachers – Pathway

The Physics Teaching Web Advisory (Pathway) is taking a somewhat different approach to the issue of trying to help physics teachers. Pathway, http://www.physicspathway.org/, is aimed at teachers who are already teaching. As is shown in Figure 7 many teachers have a limited background in physics and a limited background in the pedagogy of physics. Some went to the university primarily to be biology teachers, and 10 years later learn that for the first time they would be teaching physics. They have not studied what we consider very important -- how does one teach physics.

The Pathway system is web-based. It does not would require that teachers to come to any particular location. Further, our approach is "just-in-time." That is, a teacher is sitting at his or her table at home getting ready for tomorrow's class. It is probably 10 o'clock at night. He or she has just put the children to bed, and suddenly realizes he or she does not know how to teach Coulomb's law. So, we would like to provide help at that time. Hopefully we can provide help earlier also, but sometimes it has to be then.

We are working with people at Carnegie Mellon University which has a huge information technology faculty. A former physics teacher, Scott Stevens, has developed web-based software systems that we are using and developing further.

One component is a digital video library for physics teaching. We would like this component to grow into a major resource of videos for teaching physics. These video would include collections of video that teachers could use in the classroom and examples of different ways to teach various topics.

Anybody whose tried to search for video on the web knows that one of the issues is how do you display the information so somebody can learn very quickly whether or not the video is useful. We have three or four ways already. The underlying software which we are using was originally developed for television news organizations so they easily find items in their news archives. It does not quite work the way we would like yet, but we are improving it.

We still need video. If you have some teaching videos that you have made or you at least own the rights to and would be willing to share them with us, we would be glad to use them.

The other component of Pathway is based on a Carnegie-Mellon product called a synthetic interview. In this type of interview the user carries on a conversation with an experience physics teacher.

The interview is basically a virtual conversation. The user types in a question; our system finds a match to that question, by using a natural language search engine. This search is much more than picking out key words; it is looking at the input sentence structure and figuring out is wanted. Then, the software selects an appropriate audio-video response. Some of these responses will have demonstrations or examples in them – more than just somebody talking. Further, the user has a choice of the views of four different experts on each topic.

Three of the experts are shown in Figure 8. Roberta Lang is a retired teacher from the Orlando, Florida, school district. This district is an urban environment with a large percentage of students whose first language is not English. She is started as a chemistry teacher and later became almost full-time in physics.

Figure 8: Three of the expert teachers who are part of the Pathway project. From top to bottom, Roberta Lang, Charles Lang, and Leroy Salary.

Charles Lang has quite a different background. He is from rural Nebraska taught in Omaha, which is the largest city in Nebraska, and has conducted many workshops for rural teachers. Leroy Salary is primarily a teacher educator who is at Norfolk State University in Virginia, mostly in an urban environment.

Paul Hewitt, Figure 9, has written textbooks for conceptual level physics at both the high school and college level. He is not someone who has been teaching teachers, but he is known to almost all teachers. At least, they know his name because they know his books. He has about 30 years in teaching, so he certainly has a lot of knowledge about how to teach.

Figure 9 shows the screen that the users see. The teacher types a question in the box above "Ask." Then, she or he selects any one of the four people to answer it. In this case we have requested Paul Hewitt.

One of the issues is these teachers do not know physics very well. They may not know what question to ask. So, the teacher has some other options for asking questions. Once they ask a question we put up a series of questions that we think might be

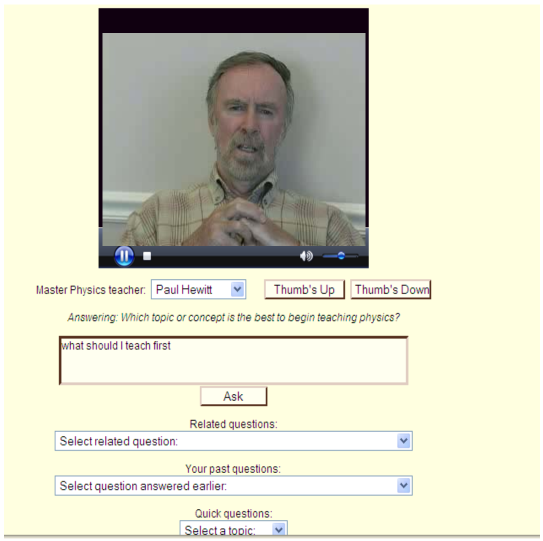

Figure 9: The synthetic Interview screen from Pathway. The expert teacher is Paul Hewitt.

related to theirs. We also keep track of their questions so they can go back and ask one again. If they really don't know what to ask, we have a list of topics that allows them to look at the some possible questions.

We also are trying to connect Pathway responses to the science teaching standards. This task is difficult because the teachers need to know connections to their state standards. Attempting to connect our responses to the standards of all 50 states would drive us crazy both because there are 50 of them and because they change all the time. So we are mostly connecting to the National Standards.

We also want teachers to know that research on physics teaching supports these responses. If we have identified research on the topic of a response, the references are provided on the screen as the response is played. It is a small amount of information, but the teacher can follow up. We hope to get those linked to appropriate journals someday soon but that's a big job that we have not done yet.

Assessing the impact of Pathway is not easy. The responses have all been positive. The data that we have collected tell us that people are using Pathway to help them prepare lessons. However, this is a voluntarily web-based system. Next year we will work with the Los Angeles school district, which is the second largest school district in the country, to undertake a more formal assessment.

10 Summary

To summarize quickly, states control teacher certification. Frequently, in all states the teachers are under-prepared. We also have an insufficient number of physics teachers being prepared by our universities. The lack f new teachers and the lack of preparation by existing ones are major challenges. We need to help people who are teaching physics and will continue to teach physics but need better preparation. At the same time we need to encourage more students to become physics teachers. To accomplish these tasks physicists need to learn from and collaborate with existing teachers and faculties of education. I've showed you two national efforts that are addressing it and we hope to know more about how they are working very soon.

11 Acknowledgements

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12 Literature

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