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## *Understanding Culture of K-12 Schools*

Bridging "the gap" was a very important point of discussion at the [RISE working conference](#). The gap is a cultural one, causing unintentional breaches of etiquette, miscommunication and frustration. The cultures of education, scientific research and business are all quite different. Therefore establishing a successful science-education partnership means the cultures must be bridged.

Throughout the website, strategies are offered for approaches that are culturally sensitive. In addition, three articles are offered here which will help provide you with an understanding of the culture of K-12 education. RISE would be interested in receiving comments and suggestions for expanding this section.

1. Caution! Your ideas about what helpful contributions you might make may be off-base. Read this article by an experienced scientist on what he has learned as participant and co-director in the successful partnership of the California Institute of Technology with the Pasadena California school district. **Scientists and Science Education Reform: [Myths, Methods and Madness](#)**.
2. Another confounding aspect of entering into a partnership with teachers is trying to understand educational jargon. A few key common terms are defined in [Translation, Please!](#). Additional resources are given for reading more about these terms and the educational theories behind them.
3. A physicist, who has devoted the last 5 years to becoming involved in K-12 science education, offers his personal views on the how the world of physics research and education differ in [Science Education Through The Eyes of A Physicist](#), an entertaining and sometimes barbed commentary.

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# Scientists and Science Education Reform: Myths, Methods, and Madness

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Over the last several years, the deplorable state of public science education and the perceived consequences for our nation's economic and intellectual vitality has attracted not only the attention of educators and politicians, but also an increasing number of professional scientists and engineers. As a consequence a remarkable number of science professionals are becoming or are already involved in attempts to improve public science education. While, in principle, this increased involvement of the scientific community is encouraging, it is also the case that scientific training often includes little or no focus on science education itself. Instead, it is simply assumed that a PhD in experimental science is adequate preparation for ones eventual educational responsibilities. Based on ten years of involvement in elementary science education reform, I can assure you that this is not the case.

For the last eleven years, myself and my Caltech colleague Dr. Jerry Pine have been involved in a close collaborative partnership with the Pasadena Unified School District in an attempt to introduce and support high quality inquiry based "hands on" science teaching for all children. As of the fall of 1993, all 650 K-6 teachers in this large urban school district teach 4, 10-12 week science units each year. These units emphasize an open ended experiment-based approach to understanding science. We have also developed a substantial professional development program in science for all teachers in the district as well as an extensive materials support system. Program extensions are now being made into middle and high school classrooms as well as preservice teacher training. Over the last five years, we have also transplanted this project into two additional school districts, one in California and one on the island of Maui. As a result of these successes, in the fall of 1994, the National Science Foundation established a center at Caltech intended to transfer our model for systemic reform to 14 new school districts in the state of California. At present we are working with 9 new school districts located throughout Central and Southern California.

## "Myths" of science education reform

While I believe that our efforts to change science teaching in public schools have met with some success, this success absolutely required that I, as a scientist, reexamine many of the most basic educational assumptions I had developed as a result of my own science education. While I started these projects 10 years ago with enthusiasm and a sense of great need, I realize in retrospect that I was, in fact, poorly equipped for my role as a partner in change. I knew essentially nothing about education in general, or science education in particular. Many of the assumptions I had made about the change process, as well as what good science education looked like, were flat wrong. I also had little or no real understanding of the structure of school districts, teacher capabilities, or the effort really required to produce lasting change in public science education. Ten years later I continue to learn important lessons regularly, guided by our school district collaborators.

Nevertheless, based on the initial success of the Pasadena projects, I am increasingly asked to evaluate other science reform efforts involving scientists. From this exposure it has become clear that many of the incorrect assumptions I myself initially made are often evident in the plans of other science education reform efforts involving scientists and scientific organizations. In fact, these assumptions appear to be strong enough that scientists often invent nearly identical science education reform programs often with limited success. The purpose of this article is to explicitly identify some of these "common myths of science education reform". While several of the points made will probably be regarded as controversial, at a minimum this listing will expose potential reform advocates to several important program design issues. After all whatever the final structure of a particular program, no program, just as no research project, should be created or run in a vacuum.

## **Myth 1 - The problem with public science education is that a large percentage of teachers are incompetent.**

It is remarkable how widespread the view is that teachers, especially in early grades, are minimally functioning human beings. It is also remarkable how rapidly this notion disappears when one becomes seriously involved with teachers and the worlds they live in. Teachers in California public schools are now expected to manage the learning of 30-40 students per classroom with almost no outside help, and almost no budget. It is absolutely remarkable that more of them do not quit outright. The reason they do not, in our experience, is that almost all of them have a deep personal commitment to student learning. With such a commitment, and a rational approach to science education reform, we have found that the vast majority of teachers enthusiastically participate in improving the quality of science education.

## **Myth 2 - Teachers are under motivated to teach science because they do not understand how exciting it is.**

When surveyed teachers actually report that they already consider science to be one of the most exciting contemporary fields of study. However, attempts to transfer the excitement of science through lectures never give teachers the opportunity to experience the thrill of doing science themselves. Instead, science is presented as the purview of the elite. Even programs that combine "science excitement lectures" with later "hands-on" experiments usually reinforce unproductive attitudes. For example, in most cases, the "hands-on" activities are do-it-yourself "cook-book" demonstrations of the sort professors design for their own undergraduates. These are usually primarily intended to assure that everyone gets the same, right answer. This type of lab is in sharp contrast to inquiries which give teachers opportunities for real open-ended scientific discovery. Obviously, they also reflect that fact that in "real science" the answer is often not simple, singular, stable, or in many cases even known.

## **Myth 3 - The primary reason teachers do not teach science well is a lack of science content knowledge.**

It is perhaps not surprising that many programs run by scientists focus on increasing the scientific content knowledge of teachers. In my view this directly reflects the structure of undergraduate and graduate level science education which is most often predicated on the assumption that a strong understanding of science content is a necessary prerequisite for eventual success in research. While I personally doubt that this is true even in higher education, in the context of K-12 science education reform, there is no question that an inordinate upfront focus on science content only reinforces the inadequacy many teachers already feel about their own science content knowledge. This, in turn, reduces the likelihood, especially in younger grades, that teachers will actual teach science.

When the focus of science education is changed from science content, to science process, the hesitation of teachers to teach science greatly diminishes. As teachers understand that the skills they need to teach science are not substantially different from those necessary to teach other subjects, their willingness to engage their students in real scientific inquiry increases dramatically.

## **Myth 4 - Supplemental teacher training is necessary because too few teachers especially in the early grades, have been required to take science classes in college.**

We have found that a teacher with adequate materials, enough time, and good classroom and science experiment management skills can actually provide their students with an excellent science education with remarkably little science content knowledge. In fact, in general, the more college science courses a teacher has taken, the more likely they are to model their teaching on the lecture-based approach of most university science professors. Accordingly, teachers with fewer college lecture-based science courses are often more amenable to fundamental change to inquiry teaching methods than are those whose examples for science teaching come from college and university professors. In our experience, as these teachers become involved in real science experiments in their classrooms, they inevitably seek additional science content knowledge. However, in this case the information they seek is directly related to their own needs as science teachers, not to lists of "what all teachers (or students) should know" generated by others.

## **Myth 5 - The key to scientist involvement with teacher training is to provide complex information in as digestible a form as possible.**

It follows from my previous statements that distributing simplified scientific information is about the last thing that a scientist should do. Watered down lectures only serve to reinforce in teachers the sense that they are not really capable of understanding scientific principles, reinforcing the insecurity that many teachers already feel about science. As I have also stated, scientific information in this form is almost worthless to teachers in any event. Young students, unlike those in college and graduate school, have not yet learned what questions not to ask, and therefore will rapidly expose holes in the knowledge of a teacher trained to be a "mini-expert". In fact, these students regularly expose holes in my own scientific knowledge. On the other hand, if the role of the teacher is as a guide to students in their own scientific investigations, then the lack of detailed knowledge of the teacher is a source of motivation and ownership by students. Of course, this change also substantially alters the role of the scientist in educational reform. The "classroom management" skills now required to organize time and materials or help students work in cooperative groups are not something that most scientists know anything about. However, what scientists do know about is how to conduct investigations. Accordingly, in our programs the primary role of the scientist is to model inquiry, not to fill in teacher backgrounds. Just as we are comfortable guiding our graduate students to explore subjects for which we do

not yet know the answer, teachers should be comfortable guiding their students' explorations.

## **Myth 6 - The problem with science education is a lack of good curriculum and therefore we must develop it.**

If the emphasis of the reform project is on grades K-6, this statement is absolutely wrong. Over the last several years, numerous companies have begun marketing excellent early science curriculum. In fact, I believe that, at this point, there is almost no need for further curriculum development in K-6. Instead, reform programs should focus on how to implement and support the use of this existing curriculum.

Beyond the elementary school level, however, there is as yet almost no good, readily- available inquiry-based curriculum. This is one of the many reasons that I believe reform efforts should begin in elementary school. The vast majority of what is available in higher grades is either fundamentally lecture based, or based on "cook book" hands on activities intended (as in our undergraduate laboratories) to assure that every student gets the "right" answer. As I have stated, enforced "correct" answers should have no place in real science education.

This said, however, the answer to this problem is NOT to have reform efforts develop their own curriculum. Curriculum development is a much more costly and time consuming process than most scientists believe, requiring long-term revision, field testing and evaluation by a highly-talented, motivated, and educated development team. A reasonable estimate of the cost of developing a real 12-week curriculum module for elementary school, for example, is \$400,000 and three years. Curriculum developed in the context of reform efforts is often mostly of the demonstration variety that does not support good inquiry teaching. Further, an emphasis on curriculum development tends to underestimate the far more difficult problem of curriculum support and implementation. Many millions of education dollars spent on "grass-roots" curriculum development programs have not corrected the perilous state of science education in our schools.

## **Myth 7 - One reason to develop new curriculum is to introduce modern scientific techniques derived from current laboratory experiments.**

It is my view that the drive to make curriculum "modern" is misplaced. While

understanding the political and social implications of modern science is clearly important, a specific focus on this objective often indicates a hidden agenda. For example, a teacher training program in modern biology might be intended to directly counteract the effectiveness of animal rights activists. Such political considerations, when they are primary, often directly undermine the open inquiry process that is supposed to define scientific methods. It also places science training programs at risk of using the same tactics as those they are attempting to counteract. Further, modern experiments and experimental techniques are often not accessible to deep process knowledge or active exploration; instead, they infrequently come across as being more magical than scientific. Classroom activities developed from research laboratory experiments, in particular, are very often only simple demonstrations of previously presented science facts. Such activities bear little resemblance to real experimental science and seldom support inquiry-based learning.

In my view, any subject considered as a base for science curriculum should be evaluated for its value in teaching and learning, not solely for its degree of contemporary content. While questions of relevance are often important to teachers and students, especially in higher grades, we have found that any real scientific investigation, correctly conceived and supported is regarded as a valuable experience.

## **Myth 8 - Training a few highly-motivated teachers will produce "trickle down" reform when they return to their schools.**

Regardless of the emphasis on content or process, the most common form of educational reform project is one that assumes that a small number of highly-trained teachers will transfer their abilities and enthusiasm to other teachers in a school or district. Again, this approach to educational reform reflects the hierarchical structure of science education in universities. In fact, there is little evidence that individual training courses have much effect outside the classroom of the trained teacher. Teachers that have elected to take these courses are often regarded as "special teachers" by other teachers, in effect isolating them from their colleagues, and reducing their effectiveness as reformers. Further, real teachers seldom have the means or time to support or transform the teaching techniques of their colleagues.

If systemic change is the objective, then it must be the specific target not an assumed side benefit. In Pasadena, our initial focus on all teachers, not just the recognized mentor teachers, in a single school produced the local proof of concept necessary to convince the rest of the district to make the change. The fact that the majority of teachers in the initial school were enthusiastic about the program, in effect, certified for the other teachers in the district that this was something that they too could do. As we now move into other school districts, the

primary problem is slowing down the implementation, not convincing other teachers to try it.

### **Myth 9 - If teachers are motivated enough during training, they will find a way to obtain the material necessary to teach science in their classrooms.**

Over the last several years, there has been a clear migration away from lecture-based instruction towards more hands-on approaches. Unfortunately, however, most programs supporting this change still do not take into account the need to provide material support to teachers back in their own school districts. In fact, far too many university-based programs seem to assume that participation in a summer workshop will provide the necessary teacher motivation to change classroom instruction. There is little evidence that this is true. Instead, to be effective a program needs to take into account, at the outset, that in-district support and follow-up will be necessary for success. This is particularly true with respect to science instruction materials. Very few public schools in the 1990s have budgets that can support the materials necessary to teach science well. Teachers often do not have the political clout necessary to obtain what minimal money is available. For most of our teachers today, teaching is a lonely and personally expensive occupation. If a program intends to maintain a lasting commitment from the teachers it has trained, direct and continuing school district support is essential. The lessons of the last 30 years make this absolutely clear. The wonderful hands-on materials developed in the 60's remained completely unused without support for the material and professional development needs of teachers. Unfortunately, this means that school districts as well as project coordinators have to deal with the nuts and bolts issues involved in supporting real experimental science at the beginning and throughout a project. Without this support it is well known that good science teaching can not be sustained.

### **Myth 10 - Reform can be accomplished with existing resources if they are simply allocated more efficiently.**

In my view, this is perhaps the greatest myth of education reform. While it may be the case that 30 years ago resource allocation could fuel reform efforts, it is no longer the case today. Public school districts, especially those serving poor children (i.e. districts that can not rely on direct parental financial support) have been cut so close to the bone that there is little money left to support even the existing curriculum. With cuts in social services, these school districts are rapidly becoming social service agencies, rather than educational institutions. The basic

health and safety of their students inevitably takes priority over something as relatively esoteric as science education, let alone its reform. For this reason, no matter what else happens, if public schools continue to be denied the resources they need, no reform effort will be sustainable, and the cultural, educational and political spiral we find ourselves in now will continue. As an advocate for science education reform, I now also spend considerable time evaluating educational projects in third world countries. It is becoming increasingly difficult to distinguish schools in these regions of the world with our own public schools. As the richest and most economically vital country in the world, there is no excuse for this situation.

## What can I do as a scientist?

While the forgoing list of "don'ts" might be daunting, in fact, I believe that scientists should be encouraged to get involved in science education reform. Scientists can play a critical role in the process of reform, even if the role they actually play is somewhat different from the role they imagine they should play. The following partial list is based on our experience with several school districts and the many scientists involved in our programs.

**Program Validation:** Perhaps surprisingly I believe that the largest contribution the scientific community can make to science education reform is related to the popular perception of scientists rather than their scientific knowledge directly. Through involvement in a reform program, scientists can certify the validity of a program. For teachers, parents, administrators, students and even funding agencies, the involvement of real working scientists in a science education program can lend essential political support for a project. While this political clout may be a result of what, in my opinion, is the mistaken public impression that professional science content knowledge is a critical component of any science education reform effort, it provides scientists a tremendous opportunity not available to many other sectors of society (or members of the traditional educational community). Of course, this makes it especially important that we use the opportunity wisely.

**Teacher support:** The involvement of working scientists can have a profound effect on teacher optimism. Changing teaching style and/or adopting new curriculum requires tremendous energy and commitment on the part of the teachers involved. Through supportive participation in the process, scientists can provide crucial emotional support for teachers and also advocate for teachers within a program, school district, and/or community.

**Resource acquisition:** To be a professional scientist in today's world, it is necessary to have exemplary grant-writing and

communication skills. Such skills, or the time to use them, are often lacking in school systems. As the current financial conditions of most public schools make the need for outside funding of reform projects critical, scientists can provide an extremely valuable service as grant writers and administrators. Without outside funding, today's reality in public education virtually assures that innovative programs can not exist.

**Modeling the scientific process:** While scientists must be very careful in the use of their content knowledge, real science whether in the laboratory or the classroom depends substantially on the application of good scientific process. By scientific process I do not mean the famous four steps in the scientific method that are drilled into the heads of children from grade 3. Instead I mean the real scientific skills of investigation, critical thinking, imagination, intuition, playfulness, and thinking on your feet and with your hands that are essential to success in scientific research. We have found that trained scientists, properly prepared and with attitudes adjusted, can easily apply these skills independent of their particular area of expertise. In fact, in our programs we intentionally assign scientists to teacher training groups outside their area of expertise to reduce the likelihood that fun and exploration are replaced by a quickly offered factual answer. In our experience, when scientists and teachers are mixed together in inquiry teams where no one has the answer (or better yet, where a "correct" answer does not even exist), the result can be extremely valuable for teachers. There is no more effective means to convey the excitement of science than to let teachers and their students really do science where doing is dependent on involvement in an open-ended, inquiry-based, student-driven exploration of almost any subject.

## In Conclusion

**All Teachers, All Children:** The myths I have considered in the previous sections are obvious and understandable given the type of science education most scientists themselves have encountered. However, there is another myth that is perhaps more sinister and deeply buried than these and that is that only a select subset of our society can really be involved in scientific exploration. In this view the rest of our society simply become consumers of scientific facts. Those programs that focus on exceptional teachers or on the so-called gifted, reinforce elitist views of who can and can not do science. Our experience in the elementary school grades of the urban and predominantly minority Pasadena Unified School District suggests that every teacher and every child can benefit from high-quality science instruction when given the opportunity. For these reasons, I believe that effective reform of precollege science education in our nation depends on supporting the professional development of all teachers in service to all students.

To do this, it is necessary to explicitly design programs that involve entire school systems, all teachers, and all students. Any other approach effectively reinforces science as an elite subject for elite teachers and special students. We are already living with the educational and political consequences of this attitude.

**Educate and Reform Thyself:** While most of the above discussion concerns scientist involvement in the public schools, perhaps the most important personal consequence of my involvement with science education reform has been a growing awareness of how poorly I have taught my own students (c.f. Bower, 1995, *Systemic reform from the inside out: Look who's changing now. The Catalyst, #3*, NRC Press, Washington, D.C.). Prior to involvement in this project, I knew remarkably little about good science education. After ten years of involvement with precollege science, I have become profoundly aware of the negative effect the poor teaching of science in colleges and universities has on the rest of the educational system. In many ways, colleges and universities set the standards for the entire educational system. So, while I wish to encourage scientists to contribute to the public schools, the most significant consequence for students of this involvement may very well be fundamental reform in the way we educate our own students. After all, the curriculum we ourselves control should be the easiest to change.

Click here for more information on the [Pasadena Capsi Project](#).

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# Translation, Please!

Both educators and scientists routinely use technical jargon which causes mutual frustration and poor communication. Three often-used (and misused) education terms, *constructivist*, *inquiry*, and *assessment* are defined below. Hopefully, this primer will help you understand "educationese" a little better.

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## Definitions:

### constructivist

*"Constructivist learning...is grounded in four principles. First, learning is a process of students constructing their own meaning. Second, learning depends upon the preconceptions students bring to a subject, i.e., meaning they have already constructed at a prior time. Third, learning is dependent upon the context in which the concepts are encountered. Fourth, meaning is socially constructed; understanding develops through interaction between student and teacher and between the student and other students."*

*"Instruction that fosters authentic student learning can take many forms, but whatever its form it helps students (1) connect the new understanding with prior knowledge, (2) check for inconsistencies with this prior knowledge, (3) alter understandings as needed, and (4) test new understandings in yet additional contexts. It is an activity for which students must take responsibility; the teacher is there in the role of coach to help the students in this endeavor."* This second definition is from **Local Leadership For Science Education Reform**, p. 86. See #3 below.

### inquiry-based

*"Inquiry is a set of interrelated processes by which scientists and students pose questions about the natural world and investigate phenomena; in doing so, students acquire knowledge and develop a rich understanding of concepts, principles, models, and theories. Inquiry is a critical component of a science program at all grade levels and in every domain of science, and designers of*

*curricula and programs must be sure that the approach to content, as well as the teaching and assessment strategies, reflect the acquisition of scientific understanding through inquiry. Students then will learn science in a way that reflects how science actually works."* part of [Program Standard B National Science Education Standards 1996](#) .

See also Science As Inquiry in the National Science Education Content Standards for grades [K - 4](#) , [5 - 8](#) , and [9 - 12](#) .

## assessment

Simply put, *assessment* may be a synonym for a "test", or more generally as the process of determining what students have learned. In learning about assessment in science education you will come across many forms of assessment, so several terms are briefly defined here. *Authentic assessment* refers to a "test" that asks students to apply their knowledge and skills to a real (authentic) task. When such an assessment is *imbedded* it means that the authentic task is part of ongoing instruction. Students engaged in an *imbedded assessment* would appear to be doing an instructional activity, but the teacher would use the process and/or product to evaluate each student's understanding and plan further instruction.

Students are not the only targets of assessment, science programs are also assessed. In this case *assessment* may be synonymous with "program evaluation". *Formative assessments* generally refer to feedback used to improve a program in progress. *Summative assessments* refer to a process at a final point when results are measured against goals.

In assessing both students and programs, a "*pre-assessment*" is a test, interview, or set of data that measures where participants are before instruction or participation. Conversely a "*post-assessment*" is a congruent measurement after instruction or program participation.

*Alternative assessment* usually refers to methods of testing other than giving a traditional paper and pencil test. These alternatives include analysis of a portfolio of student work, design tasks or demonstrations, participation in events similar to scientific poster sessions, or oral presentations.

For more information about [assessment in science education](#) see the **National Science Education Standards**, Chapter 5.

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## Recommended Resources:

1. Scientists and engineers recommend this book about "student-centered" teaching and learning: **In Search of Understanding: The Case for Constructivist Classrooms** (Brooks & Brooks 1993), available from the [Association for Supervision and Curriculum Development](#). From the book cover: "The activities that transpire within the classroom either help or hinder students' learning. Any meaningful discussion of educational reform, therefore, must focus explicitly and directly on the classroom and on the teaching and learning that occurs within it. This book presents a case for the development of classrooms in which students are encouraged to construct deep understandings of important concepts."
2. RISE published an issue of [The Catalyst](#) newsletter on "What Does Research Say about The Learner?". This issue contains an excerpt on cognitive development written by Larry Lowery, a renowned speaker and writer on science learning and teaching, and professor of education at the University of California Berkeley.
3. Written for school district leaders, **Local Leadership For Science Education Reform** by Ronald Anderson and Harold Pratt (Kendall Hunt, 1995), can give scientists and engineers 'inside' information about the scope of responsibilities of local science supervisors. The contents include valuable strategies about developing goals for improvement, implementation and maintenance of an innovative program, developing leadership, and an illuminating section on barriers and pitfalls.
4. **A Private Universe** videotapes and professional development materials include a now classic example of constructivist learning. The original video in this series begins with tape of Harvard graduates--at graduation--explaining why summer weather is warmer than winter or the cause of the moon's phases. The explanations, usually erroneous, illustrate the surprisingly common fact that even though students are "taught" a concept, they didn't necessarily "learn" it.

Later, a bright young lady about 14 years old demonstrates that although she "knows" how the earth orbits the sun, her understanding is scientifically incorrect. More disconcerting, however, is how direct teaching of the scientific model results in a hybrid idea--still scientifically incorrect. It is a fascinating glimpse of conceptual development, which when applied to classroom practices reminds us not to assume that students arrive with "no" ideas about how the natural world works.

**A Private Universe** is often used in community presentations to illustrate the need for new methods of science teaching. These materials are available through purchase or off-the-air taping. Access the [Corporation for Public Broadcasting / Annenberg Math and Science Project website](#) for more details.

5. See "How Children Learn" (Chapter 2) in [Science for All Children](#), published by the National Science Resources Center for a discussion focusing on elementary students. The full text of this book is available on line.
  
6. Scientists and engineers curious about measuring student achievement in science have found the following book helpful: "**Active Assessment for Active Science** raises questions about what education is all about. It does this by looking honestly and broadly at the many ways that children can let us know what they are learning. Here are children seriously engaged in trying to understand how the material world functions in all of its diversity. How can a teacher appreciate their efforts and accomplishment, in order to decide how to take their learning further?" from the foreword by Eleanor Duckworth. Information about obtaining this book by Hein and Price (1994) is available from [Heinemann. Publishing](#).

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# Science Education Through the Eyes of a Physicist

Ted Schultz

**About the Author.** *The author received a Bachelor of Engineering Physics from Cornell University and a Ph.D. in theoretical physics from M.I.T. In his career as a scientist, he worked as a theoretical condensed-matter physicist at the IBM Thomas J. Watson Research Center and was elected a Fellow of the American Physical Society. During this period, he also taught at New York University and the University of Munich. His more recent career in science education started at the National Science Resources Center in Washington, DC and has continued in projects concerned with the involvement of scientists with science education at both the National Research Council and the American Physical Society.*

**Introduction.** As a theoretical physicist who now devotes full time to trying to involve scientists in science education, especially in the elementary grades, I have found that the world of education is very different from the world of physics, and probably from the world of science or engineering. The environment and challenges in the two worlds are entirely different. So are the vocabulary and even the sociology. But, surprisingly, there are also a few ideas in elementary education reform that are more natural for physicists than for educators.

Any scientist (or engineer) working in both worlds or wishing to make a transition from one to the other, will have to learn about the differences. From the "constructivist" point of view, of which science educators are so fond, the scientist making this transition must construct his or her own understanding of these differences. These observations presented here are offered to help that process along.

Any educator who is involved in a partnership or collaboration with scientists may also find these observations useful. Coming to understand some of these differences, if done the hard way, could otherwise be a slower and more painful process.

**1. Complexity. The educational system is far more complex than are physical systems.** This is true for a number of reasons:

The educational system has many organizational levels (classroom, school, school district, state, nation) and each has its own administrative structure (teacher; principal; science specialist or curriculum coordinator, superintendent, and school board; state department of education; and U.S. Department of Education). Furthermore, the parts of the system at different levels interact so strongly that it is difficult if not impossible to ignore those interactions. Physical systems may also have several organizational levels (elementary particles; nuclei; atoms and/or electrons; molecules; gases/plasmas/liquids/solids; macroscopic objects; electric, magnetic, and gravitational fields; Earth, the solar system, stars, and systems of stars; etc.), but it is usually possible to focus on one or two of these levels and ignore the rest in any single investigation.

The educational system also has numerous side branches that play important roles (e.g. teacher training institutions and departments; science departments at colleges and universities; educational research organizations; educational testing organizations; educational materials developers and publishers; educational advocacy organizations devoted to a wide and often conflicting range of issues; and funding organizations). Physical systems also have side branches (e.g. the measuring apparatus, stray electric and magnetic fields, the environment as a source of heat, etc.), but they are much fewer and their effects are easier to determine and control in precise ways. [This is not to say that physicists don't have to involve themselves with public concerns, political personalities and organizations, and funding organizations, but for most purposes, this is an ancillary activity, not "doing physics".]

The "elementary particles" of the educational system are highly varied, often uncharacterizable, and usually unpredictable: people. By comparison, the elementary particles in physics, although mathematically difficult to describe, are by comparison far simpler and in a certain sense, completely predictable.

Participating subsystems in education work at more than one logical level. Teachers, for example, not only teach children, are taught by science educators, and are managed by school administrators, but they also join professional societies and unions, form advocacy groups, serve on assessment panels, etc. Electrons, by contrast, respond to a field in a definite way and don't, at the same time, stand back, observe, and fold into that response how they think the field wants them to respond and what they want the field to get out of the interaction.

In the educational system, there are many different kinds of school districts. For example, there are big-city districts, suburban districts, and rural districts; there are rich and poor districts; there are districts coinciding with all kinds of political subdivisions like a state (Hawaii), counties, cities, and townships, and there are school districts that are coterminous with no other political entity; and there are districts with a wide range of degrees of local autonomy from centrally administered districts to those with "site-based management."

The educational system also has many conflicting stakeholders: pupils, parents, teachers, school administrators, school boards, state departments of education, national administrators, advocates and lobbyists, higher-level educational

institutions, teachers of education, educational researchers, and politicians at all levels. Physical systems don't have stakeholders (until electrons develop a will of their own). The world of physics has stakeholders, but their variety is much less, and so is the contention among them.

In education, there are no sharp reliable rules, much less laws, that characterize the behavior of any of these subsystems or their interactions. In physical systems most of the rules are known and the systems are, in principle if not in practice, predictable.

The educational system is very large, and because of its great inhomogeneity, seems much larger still. It has 51 "state" jurisdictions, 16,000 school districts, 100,000 elementary schools, 1,400,000 elementary school teachers (most of whom have had little education in science, almost none of which was the kind we would hope they'd imitate in their own teaching), and about 24,000,000 elementary school pupils. Typical physical systems have of the order of  $10^{23}$  particles, which is far larger than any for the educational system, but the number of different kinds of particles is small (e.g. electrons and nuclei) and particles of like kind obey identical laws.

**2. Measurability and Predictability. In education, nothing approaches being as measurable or as predictable as in science.** This has enormous consequences.

In physics, the relevant quantities, like energy, mass, length, time, and charge, are all measurable, some with great precision. In science education, the most interesting quantities like the knowledge of science, ability to do science, outcomes of education, ability of teachers to teach science, etc. can be "assessed" (the jargon word) only very crudely.

In physics, the effects of the interactions among particles or among more complex systems are often predictable, sometimes with surprising precision. This breeds confidence that sometimes borders on arrogance. In science education, by contrast, the results of teaching in a certain way, or using certain instructional material, or instituting a certain educational program, are predictable only crudely, if at all. The inability in education to say with confidence that this is better than that, and certainly to say by how much, leads, I think, to insecurity, defensiveness, proofs by handwaving, and political maneuvering on a scale that is totally foreign to physicists.

Physicists are constantly disagreeing and questioning; tell a physicist you've discovered something and he (there are very few *she*'s) immediately tries to find the counterexample. The arguments get rather hot, but the end result is usually a defensible conclusion, or at least an agreed strategy to test different proposals. Among educators, because defending conclusions is much more difficult, disagreement and questioning are seen as more personal and threatening, so educators avoid confrontation and are usually both friendly and caring. Differences, if resolved at all, are often resolved by appeals to authority.

While there are fashions in physics, they are usually fashions of what is considered interesting, not of what is believed to be true. Our understanding of the physical world progresses in one direction; rarely do we revert to a position held and abandoned long before. In education, where what is "true" is much harder to agree on and even harder to measure, fashions are much more common, and old views do return.

**3. Immediate Answers vs. Many-year Waits. In physics, the interesting results of an experiment usually occur within days, sometimes within microseconds; in education, the ultimate effects may not occur for many years.** This difference makes meaningful experiments in education far more difficult. One wants to know not only the effect of instruction on the student's understanding of science and his/her development of scientific skills and habits of thinking each day, by the end of the module, and how this exposure affects the student's choices and behaviors in middle school, high school, college, and beyond. These are all important effects, and all essentially unmeasurable.

**4. Inanimates vs. Humans. Physicists deal with particles and fields; science educators deal with human beings.** As a result of this difference, feelings play little if any role in what physicists do and a very important role in what science educators do (and don't do). When I first entered the world of science education, I was astounded at the number of greeting cards, gifts, and celebrations of personal events (not to mention baby showers!). In the world of physicists, only weddings, deaths, the commemoration of major work anniversaries, and the winning of major prizes receive that kind of attention. Not only what is celebrated but what is said and what underlies entire attitudes reflect this difference. Physicists "tell", and the feelings of the person being told are usually ignored. Educators "share", and the feelings of the person with whom one is sharing are in the forefront.

**5. Substance vs. Mode. For physicists, what they communicate is far more important than how they communicate it; for science educators, it is almost the reverse.** The differences are seen in the way they communicate and the extent to which they evaluate their communication processes.

For physicists, their discoveries are almost all that matters. Papers are often badly written; talks at meetings are often compressions from what should take 3 hours into 10 minutes; and the pervasive attitude in oral presentations is "here it is, come and get it". Some real care may be taken by some physicists, some of the time (e.g. in writing review papers and books), but little is expended on how research results are first communicated.

For science educators, how they communicate (which is really a form of education) is extremely important. At a conference, reading a paper, with its carefully crafted prose and many well-turned phrases, is common, whereas physicists almost never read from a prepared text. Also, educators' concern about communication extends well beyond the preparation of presentations. At almost every kind of event, evaluation sheets may be distributed, something that

occasions no surprise and that even seems expected. If a physicist were to hand out evaluation sheets after a seminar, colloquium, workshop, or conference, it would shock the other physicists beyond belief.

**6. Children's Brains are Different. The brains of children, with which educators have to deal, are significantly different from those of adults, with which physicists are used to dealing.**

The education of children must be "age appropriate." There are certain things that a developing brain simply can not do (for example, at a certain age, little children have little notion of either space or time). What is age appropriate at each age level is something a teacher needs to know, but it's a notion that physicists implicitly ignore. In fact, physicists think if they explain something slowly and clearly enough, it can be understood by anyone. Educators know better.

The education of children should be more concrete, less abstract. Educators know that children are not only more comfortable dealing with the concrete, but are even unable to deal with the abstract, especially below roughly the age of eight. Adults are quite different, so for many physicists, the more abstract the better!

**7. Questions and Answers. For physicists, asking the right question is most important; for elementary-school teachers, having the right answer often is.**

This statement is of course an oversimplification, but there's more truth than might first appear. For the research physicist, good questions are the crux of the enterprise. Research is a continual quest. The answers, when found, are certainly interesting, especially when they allow the quest to go on, and they are what gets published. But it is the unknown, not the known, that is most intriguing. For many science teachers, questions are threatening, especially if from students. It is answers that make them most comfortable and that they are used to dispensing. This is not to say that physicists, when asked a question by almost anyone, don't just dump a lot of facts; they usually do. Or that undergraduate science education is inquiry-centered; it usually isn't. But it's changing, because many physicists know that they do their best teaching when they are working together with their graduate students, near the frontier where they themselves don't know the answers.

This difference has important implications for the nature of experiments and the nature of inquiry-centered teaching. Experiments should provide answers to unanswered questions, not simply confirmation of known results. Physicists know this, although they often ignore it in educating undergraduates. For traditional teachers, for whom experiments, when they occur, are often just demonstrations and are rarely to answer questions, this principle is novel, and was almost certainly not followed in their own science education. Thus, for physicists, inquiry is natural, at least when they are in their research mode. For

teachers, inquiry is unnatural. Given how hard it probably was for the physicist to learn to be a true inquirer, it is not surprising how difficult it is for the teacher who is trying to learn to teach children in an inquiry-centered way.

### **8. Collaboration vs. Solos Performances. For physicists, research is usually collaborative; for teachers, teaching is usually a solo performance.**

For physicists, research is most often collaborative if only because it is synergistic; an obstacle that is impenetrable for one member of a team, is easily hurdled by another. The give and take among a few theorists gathered around a blackboard for several days, arguing, suggesting, trying, rejecting, conjecturing ... that's the way much if not most theoretical science is done. And the apportionment of responsibilities by expertise is standard in many branches of experimental science. In a recent issue of a preeminent physics journal *The Physical Review B*, 95% of the papers have more than one author, and the joint authors are usually close collaborators at a single research institution. Also, the collaboration among physicists is not just within the same discipline and at the same institution. Interdisciplinary teams are becoming more numerous, and inter-institutional interactions, even collaborations, among physicists, who were among the earliest users of the Internet, have led to both the automated electronic exchange of preprints and more recently to the invention of the World Wide Web.

For teachers, the time, flexibility, and administrative support needed to make real collaboration the norm are all scarce. Their schedules are tight and non-meshing; they often have neither Internet access nor even a telephone; and financial support for attending meetings or even observing other colleagues is usually not there. There is an increasing recognition of the need of teachers to collaborate but, to a large extent, teachers are isolated; what they give are solo performances. To me as a physicist, this was one of my biggest shocks when I first became exposed to the education world.

### **9. Collaboration among Students -- also to be encouraged.**

Physicists know from much experience that effective collaboration while efficient is not easy to learn. To us, the idea of encouraging it among children is obvious and natural: the sooner we encourage it rather than inhibit it, the better. In the traditional education of children, where it has been thought important to be able to evaluate each pupil individually, collaboration among children has been discouraged, and sometimes even punished, although that, too, is changing.

### **10. World Stage vs. Single Classroom. Physicists and educators perform on different-sized stages.**

Not unrelated to their very different opportunities to collaborate is the very different stages on which physicists and educators "perform". Physicists who are able to publish the results of their research perform on a world stage. What they publish in an American journal (or even more, the preprint they circulate

electronically from a server in Los Alamos or Trieste) is read by other physicists in Moscow, Madras, Madrid, and Minneapolis (not to mention Marseilles, Manchester, Munich, and Montevideo). It will be discussed at national conferences in a few months, and perhaps at international conferences not long after. Real collaborations will start among people who have never even met one another.

For the school teacher, a discovery may never go beyond her/his own classroom, certainly not beyond his/her school. If there are 10,000 teachers attending the annual meeting of the National Science Teachers Association, there are at least 1.4 million teachers who are not there, most of whom are not even members of the NSTA and will never be at such a meeting.

This incredible difference between the stages on which physicists and teachers perform and a host of different attitudes it fosters should not be ignored.

**11. Teamwork vs. Hierarchy. The leader as coach, or even colleague, rather than as a didact, is as natural to physicists as it is foreign to many teachers.**

For scientists or engineers, the leader of a research group or team is often like a playing coach. It is in this position that he/she gets the best feel for what the research program is doing and the best opportunity to make his/her own scientific contribution. This cooperation is also a great leveler, strongly opposing any tendencies toward a hierarchical structure.

For teachers, to lead is to be out in front, set the agenda, determine what is taught and how, provide the necessary information and even materials. In this sense, some teachers do lead, but more often they are led, these decisions are made for them. The result is a hierarchical structure that pervades much of education and that can be very inhibiting to teachers' initiative and creativity.

**12. Reinventing Wheels -- physicists avoid trying to; teachers often don't.**

Physicists, perhaps because they are practitioners of the most fundamental of the sciences, are notorious for trying to reinvent wheels -- new and more interesting wheels, perhaps, but wheels just the same. But even they know that their science is part of a mammoth structure, and that there is too much to do in the future to be reinventing or rederiving what was done in the past. They pay a great deal of attention to much of what has been done.

Some educators know this, too. But many others spend summers "developing curriculum" and many subsequent years faithfully using the results of their efforts. It becomes a sign of "ownership," "individuality," "self-empowerment." Yet there are instructional modules that have involved many of the best minds, drawn on the latest cognitive research, and cost hundreds of thousands of dollars, whose existence is often ignored in favor of the home grown, almost as a matter of principle.

### 13. Teachers' Professional Development. Physicists, teachers, and the National Science Education Standards have three quite different views.

The physicists' view of what elementary-school teachers are is usually based on a few images from their own youth or from their children's teachers of previous years. These images, snapshots in time, give no sense of how teachers grow over the years. In this view, teachers just *are*, they don't *become*.

The teacher's view is that his or her growth comes from experience, inservice courses, summer institutes, advanced credits, and *trying harder to get better* ... until burnout. A teacher picks up many things from many places, but how they are used is strictly pragmatic: try them, and if they work, use them, somehow. In this view, research journals, whether on cognitive development, how children learn, or the effects of different instructional strategies, are for another community, the research community, not for the practicing day-to-day teacher. This is reminiscent of how medical doctors functioned at the turn of the century, when the science of medicine was still primitive, but it certainly troubles the physicist, who wants to see the latest discoveries and understandings always being applied.

Deep in the Professional Development chapter of the *National Science Education Standards* is [Professional Development Standard C](#) (p. 68), which articulates the view that teachers should be lifelong learners who use many of the processes of science in improving their own teaching, both individually and collaboratively. These processes include observation, reflection and analysis, using new tools and techniques, and paying close attention to research. For maximum growth, the Standard asks that teachers should learn to think scientifically, and use this ability to think about (and improve) their own teaching; the teacher should become a scientist about science education. To physicists, needless to say, this is a very appealing notion.

**In Conclusion.** Physicists (and other scientists, engineers, and other technical professionals) can make important contributions to science education in many ways. But to do so, they must enter a very different culture. To make their involvement useful in any real sense, they must understand the underlying features of that culture and not assume that those features are similar to those of their own. Educators will say that physicists will understand this only when they have constructed the understanding for themselves. These observations are offered as a set of pointers to aid this constructivist process.

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