Preparing K–12 Students for the New Interdisciplinary World of Science

RUSSELL A. HULSE[1]

University of Texas at Dallas, Richardson, Texas 75083; and Princeton University, Plasma Physics Laboratory, Princeton, New Jersey 08544

The increasing importance of interdisciplinary science brings with it the need to consider what impact this has on the educational process. Such considerations extend even to the earliest educational years of K–12, and also exhibit a strong overlap with many issues involved in improving science education across the board. I will offer some general remarks, followed by a focus on three educational objectives of importance to interdisciplinary science as well as to improved science education as a whole. I will close with a brief discussion of the challenges involved in implementing such ideas in the educational system. Exp Biol Med 231:1192–1196, 2006

Key words: science education; interdisciplinary science

Introduction: Interdisciplinary Science in the Context of K–12 Education

Let us start by considering two questions which will help us understand the context we are working in when we discuss K–12 education and interdisciplinary science:

- Is K–12 too early to be thinking about the impact of interdisciplinary science on educational approaches?
- Which students are we talking about?

K–12 is only the first stage in a long educational process, and thus the first priority must naturally be on teaching fundamental knowledge and skills. But that said, it is also a very critical, formative time in a person's life. Attitudes and habits of mind are formed during this period, and it is important to consider this aspect of learning along with the need to convey basic factual and procedural knowledge. It can indeed be argued that instilling the most effective intellectual approaches is a fundamental objective of the most far-reaching importance, as this will determine how an individual will approach all of the challenges of the rest of their life. This is particularly true in an age where a capacity and inclination toward lifelong learning is essential to dealing effectively with a rapidly changing world. It is developing the broadly based capacity for flexible, self-directed learning and creative thought that connects these attitudes and habits of mind to interdisciplinary science.

The second question, "Which students are we talking about," is an interesting one. There is often some confusion in any discussion of improving science education that results from unconsciously lumping together varied goals. Are all K–12 students destined to become Ph.D. scientists, or, in the context of our present discussion, interdisciplinary Ph.D. scientists? Obviously not, and we need to keep this in mind. However, it is clear that all students, regardless of their abilities or eventual life paths, do need a greatly improved knowledge and understanding of science. This means teaching not only the factual knowledge that science provides, but also an understanding of the scientific approach that leads to discovery of these facts, and which then constantly works to verify and refine the fundamental truths underlying such knowledge. An informed, functional knowledge of science and the scientific process on the part of its citizens is essential to a successful modern society.

I personally feel very strongly that improving the science literacy of all students is one of the greatest challenges that our society presently faces. This challenge is not just about training enough professional scientists and engineers to remain economically competitive in an ever more competitive world, even though that is an enormously important challenge, even crisis, with which we are presently faced. Everyone in our society needs to better understand science and technology, not only for sound economic reasons but because understanding science enriches people's lives and provides them with many important life skills, along with an appreciation of some of life's deeper values. Really understanding science involves understanding the importance of truth and patience, how one effectively searches for knowledge in the midst of uncertainty, how one needs to be introspective and honest enough with oneself to test one's beliefs, and the personal rewards, both practical and esthetic, that come from developing a breadth and depth of understanding about

[1] To whom correspondence should be addressed at University of Texas at Dallas, Mail Stop MP15, 2601 North Floyd, Richardson, TX 75083-0688. E-mail: Russell.hulse@utdallas.edu

1535-3702/06/2317-1192$15.00

how the world works. These things are of vital importance to everyone, whether they become professional scientists or not.

It is the same with our present consideration of interdisciplinary science. We will naturally tend to focus here on preparing students for whom science is to play some central role in their eventual careers. However, educational goals related to interdisciplinary science have a strong overlap with the need for improved science education for all, so much of what I discuss here will be of benefit to a broad range of students. This broader benefit is realized in part by opening young minds to the richness of the full range of science as now pursued and by showing an associated wide range of approaches to problem solving and creativity. Along the way, we naturally address different learning styles, working styles, and thinking styles. In this vein, consideration of interdisciplinary science also helps show students that a career in science can involve a lot of different types of people who work in different ways, and that, moreover, they often need to work together so that their combined skills can make exciting and worthwhile things happen.

Developing a Capacity for Interdisciplinary Work

To my mind, the essential core of a capacity for interdisciplinary work is a rich intellectual tool kit, together with a mind-set which can flexibly meld creativity and discipline in the exploration of unfamiliar territory outside the comfort zone of what one has already been taught. It is about an adventurous interest in lifelong learning that does not concern itself with traditional disciplinary boundaries.

For K–12, we are talking about the first steps toward this goal, which certainly involves enhanced exposure to a broad range of fundamental scientific content as well as conveying the excitement of scientific research. Beyond this, however, is the need to lay a foundation in such overarching subjects as the varied approaches to good scientific process, systems analysis, and problem solving, complemented by development of good communication skills and the ability to work well in collaborative groups. Note that, as I remarked earlier, many of these subjects are life skills of great importance beyond their applicability to scientific pursuits.

We need to develop in kids the curiosity and instinct to look for the big picture and connections between seemingly disparate areas of knowledge, despite the (to a large extent inevitable and necessary) discipline-specific, silo approach of the standard educational curriculum, as well as, eventually, the workplace. A critical aspect of this, and one essential to interdisciplinary work, is to get outside the comfort zone of what one has already been taught and "just do it."

I will elaborate on these points shortly in more detail. But before I do, let me briefly mention my own background in this regard, so you will know better my own formative experiences as they relate to the thoughts expressed here.

I have come to realize that I am a hopelessly divergent thinker, as an education professor colleague of mine once told me. (Actually, she did not use the word "hopelessly," but I suspect it was implied, albeit in the nicest possible way.) My interests have always varied widely, unconstrained by formal boundaries of curriculum or employer. I might add that this is often not such a good thing as regards one's career. Fortunately, I might also add, my present position at UTD, where I work on community-based science education and as Associate Vice President for Research and Economic Development, is one where these divergent interests come in very handy, much to my satisfaction.

I suspect that a fair part of anyone's tendency toward divergent interests is inborn, but as with most things, life experience also plays a big role. In my case, this life experience started with my parents supporting my wide range of youthful scientific interests with approval and appropriate birthday and Christmas presents. This led to the opportunity for a lot of early, formative experiences with do-it-yourself projects, problem solving, and, of course, troubleshooting when things didn't work. Another important circumstance involved my father building a house for us with his own hands. This was in many ways the ultimate do-it-yourself project for a young kid to be involved in—and to be inspired by, as my father had no formal training in any of the skills involved, but rather learned what he needed to know from a book and from learn-as-you-go experience. I didn't realize it at the time, but all of those youthful exposures to a do-it-yourself ethic helped instill a valuable notion that one could just learn and do interesting things on one's own, even if one didn't have formal training in those areas. I think this is something which kids in today's highly structured world of study and organized "play" are often missing, and it can negatively impact the ability of even very bright students to cope with challenges that fall outside the structured learning contexts they are accustomed to.

I think you will see why I have come to realize the value of such experiences when I relate a little of my later career. A capsule description of my graduate studies goes as follows: coursework and qualifying exams for a Ph.D. in physics, followed by thesis research in radio astronomy, which involved learning a lot about digital signal processing and programming a computer completely in machine language, from device drivers on up to numerical algorithms. So doing my thesis research relied to a significant degree on doing things that I had not been formally trained to do by my graduate coursework. (While Ph.D. research often involves the need to develop unexpected new skills, I might add that such a rather marked divergence from one's formal academic training in choosing a thesis topic is an idiosyncratic approach to a Ph.D. which I would not generally recommend.) A few years later, I was off in another direction, now doing computer modeling of atomic processes and particle transport in controlled thermonuclear fusion plasmas at the Princeton Plasma Physics Laboratory. I suppose I am proof that one can do varied, interdisciplinary things for a career and live to tell the tale. There is, however, a serious point in all this personal musing: I have come to realize that success in a varied, multidisciplinary career has a lot to do with attitude, approach, and a range of life experiences, in addition to one's formal training.

So, with that background to my views, I will now discuss three aspects of preparing students for interdisciplinary work which are applicable at the K–12 level. They are:

- Depth, breadth, and cross-cutting perspectives
- Playing well with others
- Problem solving outside the comfort zone

Depth, Breadth, and Cross-Cutting Perspectives

There is no substitute for a solid grounding in the basic scientific disciplines and in the nature of scientific inquiry. However, moving into today's increasingly interdisciplinary world also means that these deep underpinnings must be supplemented with a breadth of exposures, coupled with an educational context that calls out the cross-cutting ideas as well as differences of approach and terminology between disciplines. While teaching much of this, particularly the more sophisticated content and perspectives, perforce must await college-level education and beyond, laying the foundation begins in K–12.

One way to help ensure an appreciation of the increasingly interdisciplinary nature of science is simply to take the opportunity to point out relevant examples of the integrated nature of science during the course of teaching standard material. This is particularly important because the curriculum becomes increasingly discipline-based as one heads into higher grades. One can counter the resulting natural tendency of students to similarly compartmentalize their thinking by providing salient reminders that fully understanding things in the real world often requires spanning the as-taught disciplines and that this should be kept in mind as one proceeds through one's career.

Our traditional discipline-based educational structure doesn't easily accommodate such cross-disciplinary presentations, and this can create serious implementation problems on several levels. I will return to such issues later. However, given some increased flexibility in curriculum design, one possible approach is presentation of subject matter (perhaps using team-teaching) that is specifically selected for its ability to convey this broader view of science. Presenting a comprehensive, unified overview of the nature of life on earth is one such subject, spanning as it does astronomy, physics, chemistry, biology, geology, ecology, and other subjects in an exciting panorama. Another such subject is the functioning of the human body—biology, chemistry, and physics all intertwine to allow us to be functioning creatures. Specific new technologies where interdisciplinary science and engineering are important can also serve as useful educational platforms.

Another useful approach toward laying the foundations of interdisciplinary thinking is to emphasize the notion of systems. This can start with basic systems concepts and from there build an understanding of how to approach the analysis and construction of systems that require integration of diverse types of understanding. Computer modeling is a very powerful tool for systems study, and there are software packages that can be used even in elementary school which allow students to build their own simple computer models and begin to use them to better understand real-world situations. Robotics is another powerful hands-on educational tool that can help build the basis of interdisciplinary thinking and problem solving.

Playing Well with Others

Being able to work effectively in interdisciplinary teams is certainly an important aspect of doing interdisciplinary science, and learning how to play well with others is certainly one of the fundamental objectives of early education (or at least it should be!).

Differing ways of approaching a problem are often deeply ingrained, and they can differ across disciplines. Students need opportunities to develop a comfort level working in a collaborative fashion with those with different talents, different training, and different problem-solving approaches. This includes learning to communicate well not only with those who have the same background, interests, and knowledge base as themselves but also where more conscious effort is necessary to communicate information in terms that all can understand so as to achieve a shared goal.

K–12 is certainly none too early to start to address such issues. Indeed, this is where such basic social skills must be taught, in the earliest formative years. Good interpersonal, leadership, and communication skills are, of course, more of those overarching skills which are important for life in general, not just for doing interdisciplinary science. When, later in life, the students deal with interdisciplinary teams in higher education or in the workplace, they will hopefully have acquired a real ability to deal with often difficult-to-bridge major cultural differences—such as those between theorists and experimentalists. (Just kidding—or maybe I'm really not. . .)

Problem Solving Outside the Comfort Zone

There is no more essential skill for effective interdisciplinary work than the ability to enthusiastically and effectively solve problems outside the comfort zone of one's prior training and experience.

Such an ability is necessarily based on the fundamentals addressed earlier under the heading of "Breadth, Depth, and Crossing-Cutting Perspectives." One of the most important things provided by a suitably rich intellectual background is a tool kit of different problem-solving approaches. This includes an understanding that the most effective approach to use is a function of the state of knowledge in any given circumstance and of the investigational modalities available. This in turn relates to knowing when and how to cast about for new angles of attack on a problem and developing an instinctive ability to find the most effective path forward when approaching a given problem in the face of uncertain and confusing circumstances. In addition to a well-stocked factual and procedural tool kit, one also needs the experience necessary to create the agile habits of mind—and the enthusiasm, courage, and determination—necessary to effectively work outside the comfort zone of prior experience.

K–12 is none too soon to begin guiding students toward developing these attributes, starting by instilling a lively range of interests and openness to new ideas and challenges. This will build habits of mind that will support, or even drive, students toward a broader view of life which will predispose them toward effective interdisciplinary work.

This is the sort of thing that is learned by doing, not by lecture. The basic approach is to engage students in a diverse range of open-ended projects. By this I mean projects where the requirements are specified, along with some initial background information and guidance, but that do not come with a detailed list of instructions for completion. The free-form nature of such projects should require that students learn new content and skills as the need for them is recognized *by the student* during the course of the project.

As mentioned earlier, computer modeling and robotics are two interesting educational tools that can be used to help develop such experience and skills, but such projects can, and should, take on many diverse forms. Appropriate mentoring is of course needed, but must not take the form of *de facto* doing the project for the students, and it must be integrated with grading that effectively assesses how much the students did on their own initiative and how well they developed their personal do-it-yourself creativity and skill set.

This is all rather different than the way teaching is normally approached in K–12, or in most college coursework, for that matter. It is much more like what we expect from a graduate student doing a thesis, or when giving an assignment to a capable, experienced employee. However, this similarity to the demands of more advanced academic training and of the workplace is precisely one of the reasons that earlier and more frequent exposure to such experiences is a good idea, in addition to providing a mind-set conducive to creative interdisciplinary work beyond the boundaries of one's formal training.

Implementation Issues and Challenges

Making this all happen won't be easy. To begin with, of course, these are just some ideas, which need much further thought and practical study before one can begin to implement them. And there are more basic challenges to be addressed along the way. For example, how do we get students more interested in science, in any form?

It must also regrettably be observed that as a society we are not doing well with even the simpler task of effectively conveying the basics, let alone dealing with material that requires more sophisticated pedagogical approaches. While we do need vast improvement in the basics, this does not mean we should abandon the quest for systemic change that also addresses broader challenges and effectively develops and incorporates new approaches to deal with them.

School systems face many challenges whenever any such changes of approach are attempted, as does any large organization, particularly one which deals with a critical resource—in this case, our children and our future. This is thus a huge and complex subject, well beyond the scope of this presentation, but let me mention just a couple of specific issues.

One straightforward problem is simply that the school day is finite, so adding new material necessarily impacts the rest of the curriculum. As a result, there is great value in approaches that can be cleverly designed to do double duty; satisfying existing curriculum requirements while also adding new dimensions to the educational experience.

Another issue is that close mentoring of open-ended, learn-by-doing student projects does not straightforwardly scale up to teaching large numbers of students. Even if more efficient techniques can be developed to supervise such projects, successful implementation of the ideas suggested here would require a significantly increased number of highly qualified teachers trained in these new approaches. These teachers would also need to have the ability to support the necessary ongoing pedagogical experimentation and iterative improvement to the educational process.

Present-day assessment requirements and methodologies represent another challenge. Proper assessment of the value and effectiveness of any new teaching modality is of course essential. But overly rigid or inappropriate assessment requirements can be a roadblock to implementation of new educational approaches such as those described here.

I must now quickly emphasize that I am not proposing a lessening of standards—I am just observing that in addition to more readily tested factual knowledge, there are skills and knowledge that are less than straightforwardly amenable to simple, quantitative assessment. For example, testing for an ability to carry out effective free-form problem solving in domains outside one's prior experience is something that does not readily lend itself to a multiple-choice exam.

It should, however, be noted that we address these issues of developing and assessing broader intellectual skills all the time, if not in K–12. That is why a Ph.D. requires a thesis demonstrating a student's ability to do independent, original research, with a student's success at meeting this requirement subjectively assessed by a group of experienced research professionals.

The simple, and challenging, bottom line on assessment is this: in the end, everyone teaches to the test, so if you want to be sure something is well taught, you'd better come up with a good way to test it.

I will close this section with a few words on a subject near and dear to my heart—the special role of community-based "informal" science education, meaning science museums, science centers, and other such community-based science learning resources and programs outside the schools. This important facet of science education has much to offer as a complementary path to what can be accomplished in the schools, and it deserves significant further investment of resources, attention, and creative ideas. Such community-based science education provides a unique context for self-directed, open-ended learning and inspiration, stimulation of curiosity, and conveying up-to-date information, and it can strongly support the educational goals I have discussed here. Such community-based "informal" science education also provides unique opportunities to reach broad public audiences in a social and family-friendly atmosphere. It also offers a valuable flexibility of approach, freedom from discipline-based silos, and an ability to experiment.

Concluding Remarks

One of my mantras is that in life, finding the right balance is often the key to success. It is no different here, as we attempt to address the pre-college educational requirements which flow from an increasingly interdisciplinary world of science. Some of the balancing act required here is between attention and resources devoted to:

- Depth versus breadth
- Factual content (what science has learned is true) versus the scientific process (how science determines what is true)
- Formal, structured learning versus informal, self-directed, open-ended learning

My thoughts here just touch the surface of the many very complex, difficult, and vitally important challenges that face science education today. As scientists, and as citizens, we need to do all we can to find the best path forward.