Integration of Research and Education

What does it mean and how can it be accomplished?

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Neal Lane, the director of the National Science Foundation, has recently been writing a great deal about the role of the scientist in educating the public (*Science*, February 16 and 23, 1996). The article, "Science and the American Dream: Healthy or History?", June 1996 *Notices of the AMS*, continues this same train of thought. Dr. Lane states, "I believe that the new leadership needed from the research community is to carry our understanding of science and its value into the life of own communities through our teaching, to be sure, but in many other ways as well." It is this phrase, "in many other ways", that is the real challenge to us in the research community, and it is the launching pad for this article. I would like for us to think about the role that our investigations can play in motivating our children and for causing more mathematics to be included in their curricula.

Dr. Lane points out the important fact that federal funding for science comes out of "discretionary funds". This is not an entitlement; rather Congress must be convinced that the public will benefit from this investment of the public's money. There is always this pressure between funding educational initiatives or funding scientific research. NSF certainly feels this pressure from all sides. The concern that NSF has in encouraging scientists that it funds to bring the results of their investigations to the public so that the students of our community will want to pursue scientific careers is not new. In 1993 NSF submitted a report to the Appropriations Committee of the United States Senate entitled, "On the Imbalance in the Weight Given Teaching and Research in U.S. Universities; NSF and the Changing Academic Climate". This report was submitted to this committee in response to a directive of the Senate Appropriations Committee in Senate Report 102-356 of August 3, 1992. This directive read:

> In decisions of support and promotion of university mathematics and science faculty, a serious imbalance exists between the weight given to teaching and research contributions. The Committee believes that this situation is a significant impediment to providing students with the highest quality undergraduate education. The Committee urges the Foundation to seek ways to bring about the required cultural change in U.S. universities and to recognize those institutions that serve as national models of excellence in undergraduate mathematics and science education. The Foundation should report to the Committee on its plans concurrent with its fiscal year 1994 budget.

The comments made by Neal Lane make it clear that NSF is responding to the concerns of Congress, and rightly so. This country funds scientific investigation, and it is in the best interest of this country to use the results of this research to educate the public to the impor-

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tance of science. The more community support there is for mathematics, the more likely that funding for our investigations will result. This public understanding of our research should be a responsibility of those individuals who have created that research.

The Southwest Regional Institute in the Mathematical Sciences (SWRIMS), based at the University of Arizona, is but one of the many experiments that NSF is funding to shed light on how the university researcher can become intimately involved in this enterprise, that of educating our country. SWRIMS received its initial funding in 1994 and is scheduled to run for four years. At present SWRIMS is funding projects at Northern Arizona University, Utah State University, and the University of Arizona. These projects should provide the university research community with models that allow for the integration of research and education at the university level. The notion of integrating research and education may appear strange to most of us in the research community. What does it mean? One vision for the future that NSF has enunciated is that the investigator should be involved in both the creation of knowledge and in educational initiatives.

In mulling over how to address this question of integrating research and education, of allowing the researcher the opportunity to also become involved in educational initiatives, we in SWRIMS have formulated some projects, which we are currently carrying out, and we have formulated a challenge to the research community. Can the research community repackage the results of its investigations, of the progress that has been made in recent years, so that these results or this progress can be understood and appreciated by a less mathematically prepared audience? In repackaging this new knowledge, we want to present it in such a way that the audience would come to value our subject and be motivated to pursue further mathematical studies to a level sufficient to be able to participate in today's technological society. We all fully understand that not every piece of research is suited to such repackaging. Nevertheless, the research community has a treasury of ideas, of techniques and results, that have been developed over the years. These new ideas and results should be used to educate our citizenry to the importance and relevance of mathematical reasoning. We, in the research community, know full well that it is not facts that are important; rather it is in our approach to formulating problems, in organizing and interpreting data, and that this best can be communicated by having students actively involved in doing these things.

Mathematicians are prone to stating that the ideas that they work on, the research that they carry out, is much too abstract to present to nonmathematicians. Could we present to high school students, or even to undergraduates, the basic ideas of cohomology or class field theory? This is a debatable point. Certainly there must be some thread that connects our own research to the world. And it is this thread of ideas that could be used to bring some present-day research to a wider audience.

Of course, the science community is already heavily involved in this activity. New undergraduate and graduate texts appear regularly. It is the distinct aim of these textbooks to communicate and, to some extent, incorporate the results of research and progress in mathematical thinking into the undergraduate and graduate curriculum. But SWRIMS is suggesting that this activity reach down into the K-12 community of faculty and students. In looking at the material that is presented to the K-12 community, has it been impacted by the results of our researches from the great flowering of mathematical research that has resulted from the funding of the NSF for the last fifty years? How about from this century? Or from the last century? How many times have we tried to convince someone that Euclid did not have the last word on geometry, that mathematics is not dead, that mathematics is not the study of ancient history and techniques?

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I strongly believe that it is the community of researchers who should be at the forefront of this repackaging of the fruits of our research. Who knows better than we the wonder of mathematical research, of its utility and its applicability? Just as it is wondrous to be involved in the creation of knowledge, it can be just as rewarding and intellectually challenging to figure out how best to communicate that knowledge.

I would like to put forth one idea that might lead to this integration of research and education. It is a course of action that could be taken by a group of university faculty. In many research departments, there are groups of mathematicians that form an intellectual unit. They all study one common theme. These groups usually meet regularly in seminars, oftentimes on a weekly basis, to pursue some topic of intellectual interest to the whole group. Guest speakers are brought in, seminal papers are agreed upon, and their contents are made known to the entire group through discussion. The results of these papers will, hopefully, push forward the research interests of the group.

I would like to suggest a similar, though less time-intensive, activity aimed at identifying some topics from the research area that would be suitable for repackaging. It should be the goal that every seminar that meets on a weekly basis should produce at least one topic per year that would be suitable for dissemination to a wider audience. It does not have to be aimed at the K-12 community necessarily. It might be appropriate for the topic to be introduced to college students in their first year of study. Hopefully, though, many of the topics would be appropriate for the K-12 community.

In thinking about what might be prepared, it would be a serious oversight to carry out this project without getting some input from the K-12 community. I suggest that an academic year begin with a colloquium given by a group of K-12 faculty. This colloquium would be addressed to the entire university mathematics department. The K-12 faculty would present and discuss directions in which they would like to see materials developed for their own teaching needs. Once a topic has been agreed upon by the group, a subset of the seminar should be identified to carry out the preparation of some activity that would serve to bring this mathematical idea to the intended community. The graduate students should be included in this activity. It might even be considered that this kind of activity should form an important part of their training. We should not be wedded to the notion that the end result should be a lecture. Hopefully, technology would be used to concretely understand the problem. If the topic were aimed at the K-12 community, then undergraduates and K-12 faculty should be consulted so that the material that is to be presented would be appropriate for the intended audience. It is important to point out that the individuals who prepare the presentation are not necessarily the ones who would be giving the presentations.

It is not necessary that seminars act alone. There are other seminars throughout the geographic region that are addressing the same scientific questions. This educational activity would provide an excuse for collaboration in that region. One of the side benefits to this exercise is that the university faculty would come to better understand the process of communicating mathematics to their students.

I would like to conclude with a brief outline of how SWRIMS operates. The underlying philosophy of SWRIMS is that of mathematical modelling. The scientific topic for the academic year 1995-96 was population biology, and the activities began with a research conference in August 1995. Scientists/mathematicians were invited to participate in this conference and give talks on their research. The participants were told that there would be some high school faculty in attendance and were asked to prepare their talks accordingly so that a more general audience might be able to follow their presentation. On the whole, the lecturers should be praised for their efforts and their successes in communicating their ideas. This success can be summarized by the remark made by one of the research participants: "I am inviting high school teachers to all of my conferences—the extra effort made in preparing the talks made them more accessible and enjoyable for all of us." As the conference progressed the presenters were also asked if they could suggest topics from their own research that might be suitable for broader dissemination, in particular, for dissemination to the high school community. Several presenters took the time to suggest some interesting topics.

The funds provided by SWRIMS to Northern Arizona University, the University of Arizona, and Utah State University were used to form "core groups" consisting of 2-3 university faculty, 1-2 graduate students, 1-2 undergraduate students, and 2-3 high school faculty. The funds were used to provide course release for the university faculty and graduate students and stipends for the undergraduates and high school faculty. The core groups met on a weekly basis; the meetings sometimes dealt with the mathematics and at other times with the process of how to communicate this mathematics to the high school community. Once ideas were formulated on a presentation for the high school students, the ideas were tried out in a high school classroom. The high school faculty benefitted from the mathematical discussions, and the university faculty benefitted from the efforts to communicate the material, as well as from the experience of presenting or participating in the high school presentations.

The activities that were carried out at the various sites were as varied as the sites themselves. The organizing concept used at Utah State University was that of the symbiotic relationship that exists between a research biologist and an applied mathematician. This concept led to BAMIM, the Biology/Applied Mathematics Instruction Model (contact Cangelosi or Powell at the addresses given below for documentation in this project). The research biologist designs a study in which experiments are conducted, empirical observations are made, data are collected, results reported, and conclusions drawn. The complexity of biological research studies requires the application of mathematics not only to analyze data but also to formulate mathematical models for describing scientific phenomena and recognizing patterns. The state of mind of the researcher in the biomathematics frontier is the state of mind that BAMIM would like to create in the minds of the students. The BAMIM concept was incorporated at several middle and secondary schools in Utah. For example, a life sciences class, an advanced placement calculus class, and a computer science class collaborated on several experiments. The calculus students developed mathematical models based on data from predator-prey simulations and plant growth experiments. Computer science students wrote programs to execute algorithms and run simulations.

Northern Arizona University began by developing a semester-long course for high school faculty in population biology. The notes for this course are available as of September 1996. Once the high school faculty were familiar with the concepts used in population biology (Leslie matrices, logistic and exponential growth), the core group accepted the challenge of developing material for the high school classroom that would involve these ideas. The development of this material was the responsibility of the entire group, so that university faculty spent time in the high school classroom working with the students and learning what it means to communicate mathematics in that setting. The core group presented colloquia to the mathematics department at NAU detailing the activities that they were involved in. The material that the core group at NAU developed incorporated examples from the region. Data on the population of deer in the Kaibab Plateau, as well as data on Kaibab squirrels in Arizona, were obtained and mathematical models were developed to study the populations over many years. The Africanized bee has now reached the middle part of the state of Arizona and is now a concern to those people who live in the northern part of the state. The natural question is when or if the bees will reach the northern part of the state. Several lesson plans were developed that brought mathematics to bear on the study of the spread of these bees. In all of these lesson plans, experimentation was emphasized, as well as the use of technology.

The core group at the University of Arizona began by focussing in on the notion of exponential growth. The group decided to develop very hands-on material that would result in data that exemplified the way that populations grow. Initially, only the size of the population was studied; later, structured populations came into play, and students were led through matrix calculations. The direction that this core group took was very much influenced by the research conference that was held in the summer of 1995 in Logan, Utah. The core group broke up into several subgroups, each studying a particular topic from one of the research talks that were given. There were three groups: one studying flour beetles, another studying predator-prey models, and another studying bees. I shall describe here only the work on bees.

At this summer conference James Matis, from Texas A&M University, gave a talk based on his work on predicting the arrival of the Africanized bees to the United States. This paper concerned the development of a two-dimensional stochastic model that was designed to predict when the Africanized bees would arrive in south Texas by way of the Mexican state of Tamaulipas. The model that Matis produced gave a date for the arrival that was only two months off. In order to arrive at this model, several parameters had to be estimated: swarming rate, absconding rate, death rate, and immigration rate. These parameters are different at different times of the year and also vary with geography.

The core group brought in bee experts who provided invaluable scientific insight. Several papers on bees were studied, and the group sought to integrate this material in such a way that the students would experience the process of developing a model that would capture the intricacies of the subject. Material for seven lessons for the high school classroom was produced, the lessons being entitled: "Sizing up a Population", "Practical Knowledge of European and Africanized Bees", "Hands-on Models of Population Dynamics", "A Month in the Hive", "A Year in the Hive", "An Introduction to Remote Sensing", "Modelling the Migration of Populations".

In all of the descriptions of the core group activities given above, mention is made of material that is being developed. It is important to emphasize here that the aim of SWRIMS is not to produce materials for use in the classroom. The goal of SWRIMS is to enable the researcher to better communicate mathematics. A by-product of these efforts turns out to be this material. By working with high school faculty, whose principal function it is to teach mathematics, we believe that the researcher will benefit. In fact, this is more than a belief, as we have seen this happen over and over again in the course of carrying out these activities. Even though there appear to be decreasing resources for research in mathematics, in fact there are increasing resources for mathematical activity, which includes the dissemination of mathematics. SWRIMS is but one experiment that will allow more of us in the research community to take advantage of these expanding resources.

Readers interested in learning more about the Africanized bee project or in obtaining material or information on the many different projects that were conducted by the core groups, can contact core group members at the different sites. The SWRIMS home page at the University of Arizona (http://www.math.arizona.edu/rims/rims.html) contains a listing of the core group members at the three sites. The following is a brief listing of some contacts at each site. Northern Arizona University: Terry Blows, terry.blows@odin.math.arizona.edu; Richard Griego, rjg@odin.math.nau.edu. Utah State University: Jim Powell, powell@sunfs.math.usu.edu; Jim Cangelosi, jcang@sunfs.math.usu.edu. University of Arizona: Jim Cushing, cushing@math.arizona.edu; Larry Grove, grove@math.arizona.edu; Joe Watkins, jwatkins@math.arizona.edu.

These examples serve to indicate one path toward the integration of research and education and brings us back to the remarks at the beginning of this article. What we do as researchers can have a dramatic impact on the way mathematics is viewed by the community. But we have to take the time to make this community aware of what we do. This investment in time will serve to increase the importance in mathematical thinking among our children. Just as support for basic research is defended on the grounds that future discoveries depend on laying the groundwork now, so it can be said that the mathematical education of our children depends upon the investment of our researchers in making mathematics relevant to their lives.