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A Revolutionary Model to Improve Science Education, Teachers, and Scientists

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A Revolutionary Model to Improve Science Education, Teachers, and Scientists

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To meet many modern global challenges, we need to promote scientific and technical literacy. The U.S. National Science Foundation (NSF) supports a “revolutionary” program to connect science education at all levels, from elementary through graduate school. Susan Brawley and her co-authors demonstrate how Maine has benefitted from this program. They describe the University of Maine’s NSF-funded “GK-12 STEM” program, which placed graduate and advanced undergraduate science and technology students in elementary, middle, and high school classrooms; provided equipment for the schools; and offered training and professional development for the partner teachers. The authors urge the state, universities, and school districts to continue to use this model to increase science literacy and research capacity. 🐉

Science and technology have a significant role to play in meeting many modern global challenges. To meet these challenges and assure a healthy economy, we need citizens who are scientifically and technically literate. Science education from elementary school through graduate studies is not meeting the demand for a scientifically literate populace and there have been calls for reform at all levels (reviewed by National Research Council 1996; Campbell, Fuller and Patrick 2005). One response was the Graduate Teaching Fellows in K-12 Education (GK-12) program, initiated in 1999 by Dr. Rita Colwell, the director of the U.S. National Science Foundation (NSF) (1998–2004). Dr. Colwell stated, “We have maintained a vast chasm between our elementary science and math education, and our graduate education system—all without rational foundation. We must connect these systems” (Colwell 1999). Maine has benefitted greatly from this program and, we believe, needs to continue to use this model to build our science literacy and research capacity.

THE NATIONAL SCIENCE FOUNDATION'S GK-12 PROGRAM

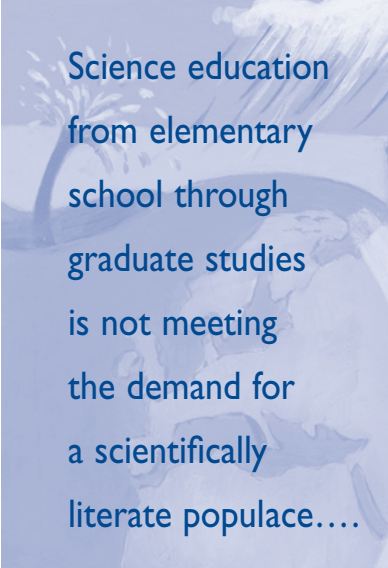
The NSF GK-12 program began in 1999 with block grants to universities, which then award scholarships to superior science, engineering, and technology students in support of their M.S. and Ph.D. studies, while requiring them to spend 16 hours per week in outreach in K-12 “to boost the content of elementary and secondary education and the quality of graduate and undergraduate education at the same time” (Colwell 1999). To ensure that university scientists supported their students’ involvement in GK-12, NSF set the salary for the scholarships at the same level as their older, signature fellowship program, the NSF graduate research fellowships (GRFs)—at \$18,000 per year in 2000—at a time when it was still common for science graduate students at many American universities to receive offers of teaching and research assistantships below \$10,000 per year. In 2003, NSF raised the awards to \$30,000 per year in an effort to attract more bright Americans to careers in science, technology, engineering, and mathematics (STEM). NSF made 253 GK-12 awards to universities in 46 states, Puerto Rico, and the District of Columbia from 1999 to 2007;

20 new awards will be made in 2008 (NSF GK-12 2008, Sonia Ortega personal communication, August 8, 2008). The three GK-12 programs funded in Maine are “NSF Graduate Teaching Fellows in K-12 Education at the University of Maine,” University of Maine (1999–2006); “A Maine Science Corps Promoting Excellence and Equity in High School Biological Science Education,” University of Southern Maine (2000–2009); and “GK-12: Sensors!” University of Maine (2001–2010).¹ Most GK-12 programs are funded at a level of \$400,000 to \$600,000 per year. Nationally, there are now thousands of young scientists and engineers who trained as NSF GK-12 fellows, tens of thousands of K-12 teachers who collaborated with a GK-12 fellow, and hundreds of thousands of K-12 students whose education was changed by GK-12.²

In each of the GK-12 programs graduate students collaborate with K-12 teachers to bring more hands-on instruction and new knowledge, not yet found in textbooks, into the K-12 classroom from the university. Explicit NSF goals for the program are

- “improved communication, teaching, collaboration, and team building skills for the fellows;
- professional development opportunities for K-12 teachers;
- enriched learning for K-12 students; and
- strengthened and sustained partnerships in STEM between institutions of higher education and local school districts” (NSF 2008: 2).

The GK-12 program was indeed revolutionary because it uses the vehicle of the graduate student to “spend” the same federal dollar on behalf of multiple constituencies (i.e., graduate education, K-12 students, and professional development for partner teachers)



Science education
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TABLE 1: Distribution of GK-STEM Outreach by Fellows (2000–2006)

District	Grade Band/H.S. Subjects ^a 2000–2003	Grade Band/H.S. Subjects ^a 2003–2006
Old Town Schools: Elementary Schools Leonard Middle School Old Town High School	3–5 6–7 Biology, Chemistry, Physics	3–5 7–8 Biology, Physics
Indian Island School (Penobscot Nation)	3–4, 6–8	3–4, 6–8
Union 87: Elementary Schools Middle Schools Orono High School	3–4 6 Biology	3, 5 none Biology
Union 90: Elementary Schools Dr. Lewis Libby (Middle School grades)	3–5 6–8	3–5 7–8
Brewer Schools: Elementary Schools Brewer Middle School Brewer High School	Not applicable	4–5 6 Biology, Earth Sciences
Bucksport Schools: Elementary/ Middle School Bucksport High School	Not applicable	5, 6, 8 Biology, Chemistry
MSAD # 22: Elementary Schools Reeds Brook Middle School Hampden Academy	Not applicable	4 7–8 Biology, Chemistry
Union 74: Elementary/Middle Schools ^b	Not applicable	3–5, 7–8
Union 92: Elementary/Middle Schools ^c	Not applicable	5, 7

^aNot every grade, nor every class/grade, was served in a single year.

^bGreat Salt Bay (Damariscotta area), Nobleboro, Bristol Consolidated, South Bristol Schools.

^cTrenton, Surry, Lamoine, Cave Hill Schools.

as opposed to traditional federal and state interventions that are aimed at only one constituency.

In practice, there are almost as many different types of GK-12 programs around the country as the number of awards. As long as universities, in collaboration with K-12 school districts, proposed strong programs that had tight supervision by university science and/or engineering faculty, the program could fit the particular area of the country or the strength/need of the university/K-12 partners. Some GK-12 programs have a narrow disciplinary focus (e.g., “Using the Native Biota for Science Education,” University of Hawaii; “Information Technology Themes in Eighth, Ninth and Tenth Grades,” Harvard University), whereas other programs cover multiple disciplines (e.g., “GK-12: Science, Technology, Engineering and Mathematics UMASS K-12 Connections,” University of Massachusetts at Amherst). We all participated in the University of Maine’s first GK-12 project (“NSF Graduate Teaching Fellows in K-12 Education at the University of Maine,” hereafter called GK-12 STEM), which was funded from 1999 to 2006 and was an example of a more broadly based program.

NSF GRADUATE TEACHING FELLOWS IN K-12 EDUCATION AT THE UNIVERSITY OF MAINE (GK-12 STEM)

University faculty from physical and biological science departments, working with the local K-12 community, prepared and submitted the grant proposal to NSF. After more than 20 meetings with local educators (teachers from grades 2 through 12, curriculum coordinators, and superintendents), we put together a proposal that was designed to provide teachers in the four districts closest to the University of Maine (Union 87; Old Town Schools; Indian Island School [Penobscot Nation]; Union 90) with the equipment and scientific expertise that they said would help them meet the requirements of the *Learning Results*, a set of specific concepts and facts that students in Maine are expected to learn before high school graduation (Maine Department of Education 1997). GK-12 STEM involved 56 fellows and 96 teachers from third through twelfth grades (2000–2006). The NSF grant provided money to purchase microscopes, pH meters,

spectrophotometers, and many other pieces of equipment that fellows carried from classroom to classroom and district to district over the six years of the project. We expanded GK-12 STEM in 2003 to 2006 (Table 1) from Greenbush to Bucksport (most of the Penobscot River Educational Partnership districts) and, in a limited-contact model explained below, to Union 74 (Damariscotta, Nobleboro, Bristol and South Bristol) and Union 92 (portions of Hancock County).

Fellows were selected via a rigorous process supervised by the University of Maine's Graduate School, which culminated with a personal interview before a final committee composed of local K-12 teachers and administrators and university science and engineering faculty. Typically, a fellow was assigned to outreach in the classrooms of three or four partner teachers. The fellow visited two or three of these partner teachers' classrooms weekly. The other assignment was a "limited contact" model, in which the fellow traveled to schools located farther from the university for the equivalent of a full day in the fall and a full day in the spring, with these classes coming to the university for an activity with the fellow between those visits.

Planning of activities and curriculum between each fellow and his/her supervising partner teachers began in a weeklong science camp held several weeks before the beginning of the fall school term. Partner teachers conducted training sessions for fellows on subjects such as student behavior and different learning styles, and fellows and university faculty delivered lectures, laboratory exercises, and field activities in different science disciplines as professional development for the partner teachers. Then the rubber met the road, and fellows began to visit the classes and carry out collaborative exercises and projects with the students that fit the partner teachers' curricular needs.

During the year, all fellows met weekly as a group with supervising university faculty. Several formal evaluations of fellows by partner teachers and of partner teachers by fellows were conducted to provide any required mid-course corrections. All personnel met quarterly for reports by different fellow/teacher teams of activities and successes in their classrooms, or for reports of presentations made by fellow/teacher teams at national and international professional science meetings. The GK-12 grant paid for most partner teachers

to attend science and engineering professional meetings during the grant period. The program allowed a single, one-year, competitive reappointment of fellows, based on our hypothesis that one to two years of outreach would provide most of the growth to the fellow.

This would make it possible to benefit more graduate students over the life of the grant and bring more diversity of academic backgrounds to the K-12 classroom. An important component of the program was that, although the program provided great opportunities for fellows to develop better communication skills, it was not conventional student teaching, and NSF required that partner teachers always be present in the classroom and be responsible for student behavior.

ASSESSMENT OF THE GK-12 STEM PROGRAM

As the first set of funded projects ends across the U.S., it is possible to evaluate the GK-12 model against the goals set by NSF for the program and to consider whether or not to sustain elements of these programs in Maine. Davis Square Research Associates (DSRA, Somerville, MA) evaluated our 2000–2006 GK-12 projects in 2007 with confidential online surveys of fellows, partner teachers, and the fellows' supervisory science and engineering faculty. All living fellows ($n = 55$), 94 percent of supervising professors ($n = 33$), and 80 percent of all living partner teachers ($n = 75$) participated in this evaluation. Selected results of the DSRA evaluation are given in Table 2 (page 72).

Effects of Fellowship on Fellows

Most (86%) of the 56 fellows who participated in GK-12 STEM have completed their degrees, with most of the remainder still enrolled in Ph.D. programs from which they will graduate in 2009 (Table 3, page 73). To date, former fellows have earned a total of 19 Ph. D.s, 18 M.S./M.A.s and 10 B.S. degrees at the University of Maine, in 23 different degree programs from civil engineering to zoology.

A key concern of NSF and all participants in the project was whether the outreach component of the GK-12 fellowship would succeed in building communication and teaching skills in fellows and at what cost—would the fellows' research suffer? DSRA reported that fellows thought the outreach component

TABLE 2: Selected Results of External Evaluation of the First NSF GK-12 program (GK-12 STEM) at the University of Maine^a

Evaluation Character	Prior to Participation (Mean/Standard Deviation) ^b	After Participation (Mean/Standard Deviation) ^b
Teacher evaluation of self: Knowledge of current science	2.68/.619	3.21*/.473
Teacher growth: Belief in students' ability to do complex science	2.68/.661	3.32*/.524
Teacher growth: Attitude toward scientific research	2.79/.703	3.53*/.528
Changes in practice of partner teachers: Experiments that include controls and replication	1.83/.760	2.68*/.661 ^c
Teacher attitudes: View of university partnerships	2.79/.793	3.51*/.705
Teacher evaluation of student attitudes: Interest in science	2.35/.688	3.41*/.548
Teacher evaluation of student performance: Scores on science exams and/or exercises	2.37/.632	2.88*/.519
Teacher evaluation of fellow's teaching skills	2.65/.726	3.48*/.601
Teacher evaluation of fellow's communication skills	2.79/.684	3.52*/.554
Fellow evaluation of self: Oral communication	2.53/.663	3.45*/.503
Fellow gains: Exposure to an interdisciplinary peer group	2.13/.840	3.18*/.641
Fellow growth: Awareness of the challenges of teaching	2.24/.816	3.71*/.497
Fellow growth: Ability to develop curriculum materials	1.98/.871	3.36*/.589
Fellow growth: Exposure to an interdisciplinary STEM peer group	2.13/.840	3.18*/.641
Fellow growth: Interpersonal skills	2.89/.685	3.31*/.573
Fellow change in practice: Public outreach	1.60/.894	2.56*/.856 ^d

^aFaculty directors of the GK-12 STEM project received only summative (anonymous) scores associated with the external review conducted by Davis Square Research Associates; the DSRA report is available upon request from the lead author. Teachers evaluated fellows' pre-GK-12 abilities in teaching and communication based upon contacts in science camp and during the first few weeks of outreach activities in the classroom.

^bScale for responses (unless marked otherwise): poor = 1; fair = 2; good = 3; excellent = 4. After participation rating significant at $p < 0.05$ by a Wilcoxin test if marked (*).

^cScale is 1 = never; 2 = once in awhile; 3 = regularly; 4 = frequently; significant with Kruskal-Wallis test at $p < 0.05$ if marked (*).

^dScale is 1 = none; 2 = some; 3 = regular, but not frequent; 4 = frequent; tested with Wilcoxin test at $p < 0.05$ and significant if marked (*).

of the GK-12 fellowship had delayed their graduation by one semester, but that significant gains in communication and teaching skills made up for this (Table 2). However, major professors found little to no effect on the quality of the advisee's research, the length of time for the degree, or change in the fellow's career goals due to participation in the GK-12 program, while reporting a great deal of improvement in fellows' teaching skills (DSRA 2007: 17). Interestingly, both fellows and their partner teachers found nearly identical changes in fellows' communication skills due to the fellowship (Table 2), whereas major professors assessed this change as "somewhat" improved (DSRA 2007: 17).

This appears to reflect gains in ability to communicate science and research to a broader audience than specialists in one's field (see accompanying article by former fellow, Dr. Peter Smith, Maine Centers for Disease Control). Typical comments to DSRA by former fellows include:

As a senior medical student, I am now responsible for teaching the first years as well as my patients. The ability to verbalize concepts to a varied population (i.e., scientists, children, parents, care-takers) was a skill I developed through my experiences in the NSF program. Invaluable. (Fellow 1, DSRA 2007:15)

TABLE 3: Career Outcomes of Fellows in the University of Maine STEM GK-12 program (2000–2006) (as of August, 2008)^a

Type of position	Fellows (total number)	Fellows (in Maine only)
Business (science-related)	3	1
Federal/state research	4	3
Industry (research scientist)	6	2
Graduate student	14	5
Homemaker	1	
K-12 science teacher	4	2
NGO research/manager	3	2
NGO science educator	2	2
Physician (M.D., D.O.)	4	
Postdoctoral research	3	1
University/college professor	11	7

^aThose still in graduate (or professional) programs are predominantly M.S.-level GK-12 fellows who are now earning Ph.D.s or other degrees (M.D.s). Data from resurvey of fellows by authors (August 1, 2008).

I am a far better teacher now. After preparing lessons for fourth graders, I can now express a concept with far greater clarity. (Fellow 2, DSRA 2007:15)

The NSF program made me a much more effective teaching assistant for University of Maine courses. (Fellow 3, DSRA 2007:15)

As of DSRA's survey in 2007, fellows had published 42 peer-reviewed professional papers, made 92 presentations on their graduate research and GK-12 outreach (many with partner teachers as co-authors), and won seven "best paper" awards at national and international meetings of scientific societies. These numbers, especially the number of peer-reviewed papers published, will increase as recent graduates continue to publish results from their theses. Two of the best paper awards were direct outgrowths of the GK-12 outreach activities of partner teachers and fellows (see sidebar, page 74), including those of Margaret Morton (South Bristol School, Union 74) and Leigh Stearns (Ph.D. student, Climate Change Institute).

Effects of GK-12 STEM on Partner Teachers, K-12 Students, and School Districts

The evaluation data reported by partner teachers in the summative evaluation indicated that school districts benefitted from an increase in science knowledge and science teaching skills among partner teachers, particularly elementary partner teachers, as a result of their participation in the GK-12 project (Table 2). For example, Margaret Morton (South Bristol School) commented,

Having graduate fellows in the classroom teaching and sharing their experiences was incredibly motivating for my students. Each year the fellows' knowledge and experiences were different and each year they were eagerly awaited by my seventh and eighth graders. Fellows taught my students computer programming, basic principles of physics, how to make 3D topographical maps, and how to model the movement of glaciers at different temperatures. The day my students spent at UM doing physics experiments and visiting the plane-

tarium with "their" fellow was a highlight of the school year. The high level of interest students had in the activities they did with the fellows and at UM obviously affected their retention of what they learned from the activities; eighth graders would often refer to what they'd done and learned as seventh graders. . . . The NSF GK-12 program provided the best professional development I've experienced. In addition to learning directly from scientists at professional conferences, contacts with graduate students, UMaine professors, and other classroom teachers have given me knowledge and techniques to use in developing lessons for my classes. A week of "camp" each summer at UMaine taught me fascinating information about Maine's geological history, marine biology, astronomy, and ice cores which I've been able to share with my students.

Another benefit to participating school districts emerged when partner teachers reported an improved understanding of the entire science curriculum in their district as a result of the collaboration with fellows,

Partner teacher Margaret Morton (left, South Bristol School) with fellow Leigh Stearns (right, Climate Change Institute, University of Maine) being interviewed for Chinese TV during the 2005 “Climate and the Cryosphere” meeting in Beijing after their award-winning presentation, “Educating K-12 Students about Glacier Dynamics and Climate Change.”

Ms. Morton commented, “In addition to explaining the NSF GK-12 program and its benefits to my students and answering questions about teaching science in the U.S., I was also asked to comment on what China should be doing to educate students about changes in the cryosphere. This professional conference was compelling and has given me an abiding interest in learning and teaching about climate change and global warming.”



university faculty, and other partner teachers (DSRA 2007: 25). The summative evaluation results and subsequent interviews with participating partner teachers also found that they continued to implement some of the lessons that were developed in collaboration with their fellows and that they continued to use more hands-on work incorporating replication and controls into science instruction (Table 2, page 72). Both of these findings are particularly beneficial to districts because they document that the lessons developed during the GK-12 project to teach the *Learning Results* are continuing and that the methodologies learned and implemented during the project’s professional development activities are continuing to support partner teachers in meeting their responsibilities for teaching Maine’s *Learning Results* in science and technology.

Partner teachers at all levels reported to DSRA that the GK-12 program made them more effective in meeting the goals of Maine’s *Learning Results* in science and technology. DSRA commented about this:

Partner teachers reported with a strong consensus (the high school partner teachers varying somewhat more) that participation in the project helped them to be more effective in meeting the goals of Maine educational standards. Using a 3-point scale, partner teachers were nearly unanimous in saying that the project was helpful in this regard. This finding is important in that, all too often, science innovations are seen as falling somewhat outside educational policy goals. In this case, the introduction of new content appears

to have helped to increase the participating partner teachers’ sense of self-efficacy in meeting state goals (DSRA 2007: 28).

It is difficult to verify this finding in student achievement data due to changes in the Maine Educational Assessment during the project years of 2000 to 2006 (Maine Department of Education 2008a) and because not all elementary partner teachers and middle school and high school science teachers in partner districts were participants in the GK-12 project. Indeed, the DSRA report ends with an explicit recommendation to determine ways to evaluate the effect of participation on student learning as measured by state tests. However, partner teachers reported favorable effects upon students (Table 2, page 72) and also reported that many of their students talked and thought about science in different ways.

One of the most beneficial aspects of the GK-12 project to participating schools and districts was the access to scientific equipment and supplies that it provided both during and after the project. Partner teachers had access to and training for a significantly expanded array of scientific equipment. When the project ended, most of the equipment purchased with the NSF funding (\$200,000, when new) was transferred from the university to participating districts, which agreed to continue training personnel to use it and to maintain it at an acceptable level. This benefited participating districts because it allowed them to continue and expand the access to scientific inquiry that was provided to students of partner teachers by the equipment and the lessons during the project years.

For example, Arthur Libby (high school science teacher, Brewer High School, Brewer, ME) commented that, “The GK-12 STEM program left its footprint at Brewer High School. The training the teachers received and the equipment to sustain that training (i.e., dissecting microscopes and a mobile molecular biology laboratory) still enhance the learning of a hundred or more students each year.” Many of the participating schools have continued to offer professional development activities, taught by partner teachers, to train new teachers to use this equipment and to use some of the lessons developed during the GK-12 project. At least one participating district (Old Town) continues training on a district-wide basis. However, when DSRA asked partner teachers whether their ability to continue some of the GK-12’s lessons was limited, they said yes. The reasons listed, in order of significance are (1) lack of equipment, (2) lack of supplies, (3) too little preparation time, and (4) need for more than one person in the classroom during the activity.

Perhaps the most important benefit of the GK-12 program in Maine and across the country is that many GK-12 programs have led K-12 students and teachers to learn science while practicing it. Young children are nearly always actively curious and experimental in learning about the world (Bransford, Brown and Cocking 1999). However, these practices are rare in many classrooms because of lack of equipment or an extra pair of hands, and/or the teacher’s need for more science background and confidence. The importance of inquiry-based teaching is widely recognized (Bybee 2002; Handelsman et al. 2004). Memorization, when not leavened with inquiry-based discovery, causes many students to turn away from science at a young age. According to Maine’s *Learning Results* (Maine Department of Education 2007), one of the major foci of science education is for students to plan, conduct, analyze data from, and communicate results of in-depth scientific investigations. The NSF GK-12 program focused on teaching students and partner teachers the correct process for scientific inquiry by involving them in authentic research experiences. This is one of the five standards in the *Learning Results* and is difficult for teachers to cover in-depth without help from the scientific community.

The range of authentic research experiences offered to teachers and students through the GK-12 STEM program matched the diversity of fellows’ degree programs, and the activity/results of several of the longer-term projects were published (e.g., Schilling 2004; Horton 2005; Muhlin et al. 2008). Filling a request that had come to GK-12 fellow Kristi Crowe (now a professional food scientist at *Southern Living Magazine*), chemistry classes at Hampden High School determined anthocyanin concentrations in blueberry leaves to help a Maine farmer to develop a blueberry tea product. Research experiences often made use of habitats adjacent to schools for projects, such as in a study of small mammal biodiversity in Sunkhaze Meadows National Recreation Area by middle school students from Lewis Libby School in Milford. Laura Matthews, a science teacher at Reeds Brook Middle School in Hampden, commented,

One year, my fellow [an engineering graduate student] worked on a bridge-building unit with our students. The students in R&D groups (research specialist, architect, materials engineer, and data analyst) researched stresses and forces, designed a bridge, built it, and tested the finished design in the classroom. Then, we took the top two bridges to the University of Maine’s Civil Engineering Department, where students tested the bridges in a stress machine.... [Each year] my fellows brought real science to our classroom with open-ended questions, research, experiments and student presentations of their findings.

The National Science Education Standards (National Research Council 1996: 28) state,

In the vision of science education portrayed by the *Standards*, effective teachers of science create an environment in which they and students work together as active learners. While students are engaged in learning about the natural world and the scientific principles needed to understand it, teachers are working with their colleagues to expand their knowledge about science teaching. To teach science as

portrayed by the *Standards*, teachers must have theoretical and practical knowledge and abilities about science, learning, and science teaching.

This quotation captures what the NSF GK-12 program was all about: it focused on increasing teachers' science content knowledge, along with focusing on the students as active learners—a safe learning environment in which the students and teachers progressed together (Lumpe 2008).

There is also substantial evidence that the final goal of the GK-12 project—to strengthen the school university connection—was met. In the summative evaluation, partner teachers reported improved attitudes toward university partnerships and an improved attitude toward scientific research (Table 2, page 72). Both of these findings should be beneficial to K-12 science education and to a major component of science education at the university level, scientific research. In addition, fellows reported that the project had opened the lines of communication between the local partner teachers and the university, and that they had acquired a new appreciation for science education, science outreach, and for the challenges of teaching. Jessica Muhlin, now an assistant professor at Maine Maritime Academy, wrote, “My partner teachers supplemented my traditional graduate education with important science pedagogy. . . . My GK-12 training made for a comfortable transition from Ph.D. student to college faculty member.” As most of these fellows move into careers as scientists, doctors, and engineers, they should continue to be supportive of science outreach and to K-12 education; indeed, this effect is already apparent in the DSRA evaluation (Table 2).

RECOMMENDATIONS

When the benefits for K-12 students, teachers, districts, science and engineering graduate students, and the university are reviewed, it is clear that GK-12 STEM was a highly effective project. Similar findings are emerging from other universities in the first cohort of NSF GK-12 awardees (e.g., at Cornell University [Trautman 2008]). Can GK-12 projects be sustained without federal funding? The pieces required to continue a GK-12-type program

after NSF funding ends are equipment, supplies, appropriate undergraduate and/or graduate students, collaborating teachers, supportive university professors, a program coordinator, and STEM faculty who are committed to building science education from elementary school to graduate school.

A bill (LD 119) that would have funded a state-wide GK-12-like program in Maine with involvement of additional UM campuses was passed by the legislature in 2005, but not funded. Thus, we have failed so far to sustain our program. A few GK-12 programs in our national cohort, however, have found a variety of state, public school, industry, and foundation funding sources that enable the programs to continue. For example, an appropriation by Hawaii's state legislature (ca. \$1.4 million) for the next two years to fund a research experience for teachers (RET) program is expected to implement the GK-12 model for providing the RET, continuing the University of Hawaii's GK-12 program by funding some graduate fellowships (Kenneth Kaneshiro personal communication, August 4, 2008). University of Hawaii faculty submitting research grants to NSF are also being urged to commit graduate students funded on regular research grants to participation in a continuing GK-12 program, a device that lets researchers meet the broader impacts criterion, one of two criteria that NSF uses in deciding which research proposals to fund. The University of Mississippi founded a Center for Mathematics and Science Education that continues GK-12 activities with funding from the university and a local foundation, the Hearin Foundation (John O'Haver personal communication, August 5, 2008). Tufts University continues part of its engineering GK-12 program through a gift by a Tufts alumnus (Chris Rogers personal communication, August 15, 2008).

To continue the spread of the positive effects of Maine's GK-12 STEM, the state, school districts, and universities must all support the shared goal of improving science literacy and research capacity in Maine. To this end, we make the following recommendations:

For School Districts and the State

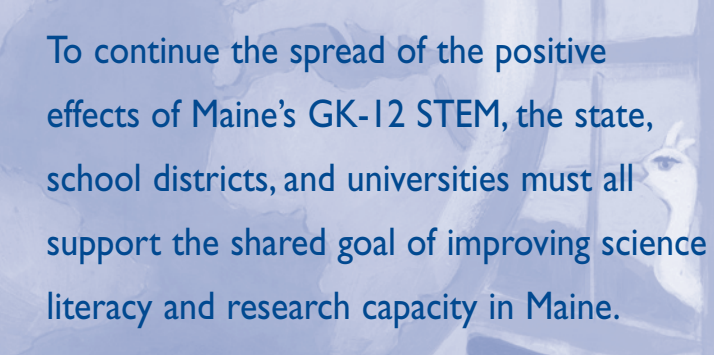
- K-12 science curriculum and professional development programs for teachers need to

- emphasize scientific inquiry and research opportunities for K-12 teachers and students.
- More hands-on scientific equipment, supplies and field trips must be made available to K-12 teachers and students. Tight budgets make this a challenge, but most districts find resources to support supplies and transportation for many extracurricular activities; academic equipment, supplies and field trips must be given greater priority.
 - Science specialists who can train teachers, identify resources, and set up a system to purchase and move scientific equipment among schools need to be hired by school districts or regional partnerships of districts.
 - Collaborations between scientists and K-12 science teachers and their classes should be encouraged and supported by schools and school districts.

The reorganization of schools in Maine into larger units (Maine Department of Education 2008b) offers perfect timing for Maine districts to consider implementing the GK-12 model of moving expensive equipment (e.g., microscopes, mobile molecular labs, spectrophotometers) among schools and sharing funds to afford or maintain this equipment. Since it is difficult for teachers to coordinate getting, moving and learning to use equipment, districts (or partnerships of districts) could hire an individual with a STEM background to manage the equipment and to offer training to new teachers. Having a science specialist to help teachers to set up labs, make reagents, and move equipment from school to school would be a key improvement in science education in Maine. Alternatively, the state of Maine might fund science mobiles to accomplish similar goals, although scheduling and coordination of arrival of equipment would be challenging.

For Teacher Professional Development

- Professional development for K-12 science teachers should imitate the authentic scientific laboratory and field experiences that were developed in this project.
- Professional development for K-12 science teachers should include collaborations among teachers from different levels, and university graduate students and science faculty over an extended period of time.



To continue the spread of the positive effects of Maine's GK-12 STEM, the state, school districts, and universities must all support the shared goal of improving science literacy and research capacity in Maine.

The statement, “The NSF-GK 12 program provided the best professional development I’ve experienced,” was repeated by multiple partner teachers and supported by their reports of increased knowledge of current science and their increased use of scientific inquiry (Table 2, page 72). Therefore, it is important to develop new professional development programs that model the GK-12 STEM programs. One such program was the authentic, field-based science activities done during the summer camps. These summer camp activities were followed by yearlong, day-to-day classroom interactions in which the teachers taught and learned science inquiry alongside aspiring and real scientists. This professional development was effective because the partner teachers had the opportunity to become personally and professionally involved in real scientific inquiry, in learning and teaching scientific knowledge that was not found in their texts, in using the equipment and resources that scientists used, and by collaborating with colleagues in real scientific research. Additionally, many partner teachers co-presented their research at science conferences.

This effective professional development can be replicated by providing more authentic and extended scientific inquiry experiences for our teachers. And, we can do this more effectively through regional partnerships among K-12 schools and the science and

engineering faculties of Maine universities and colleges. The Maine Department of Education could facilitate this model by seeking federal, state, and/or foundation funding for professional development programs for teachers. These programs could be delivered by regional partnerships of districts (e.g., the Penobscot River Regional Partnership) in collaboration with science and engineering faculties of Maine's universities and colleges that were providing "GK-12-like" fellowships or service-learning opportunities for exceptional science students.

For Universities and Colleges

- Graduate fellowships in STEM disciplines should be endowed and established to support K-12 science education outreach projects.
- Collaborations between university scientists and K-12 science teachers and their classes should be encouraged, supported, and rewarded by the university.

"For want of a nail the shoe is lost, for want of a shoe the horse is lost, for want of a horse the rider is lost" (George Herbert, *Jacula Prudentum*, 1640).

Rotating teaching assignments for teams of STEM university faculty to coordinate a GK-12 program is feasible. Finding a capable coordinator (one graduate fellowship) is doable. Funding this part of the program is achievable at most colleges and universities in Maine. But how can the STEM students who form the bridge between the university and K-12 be found? They are the nails that hold effective GK-12 programs together. Two devices appear possible based upon other programs' successes and the economic situation of Maine. One possibility is a semester-long communications requirement for a service-learning project for senior undergraduate STEM majors. Alternatively, graduate students funded on normal research grants could be required to participate for a few hours per week in GK-12-like activities for a year, to improve their communication and teaching skills (Campbell et al. 2005). A second possibility is to endow fellowships for exceptional STEM students who would carry out GK-12-like activities for one or two years.

The success of the NSF GK-12 presents us with a unique opportunity. No university in Maine, including the University of Maine, has given enough priority to raising funds for endowed fellowships for graduate students.³ The University of Maine could charge its Development Office and the University of Maine Foundation to seek endowed graduate fellowships with a GK-12 component. Each graduate fellowship could be endowed with a small stipend for a partner teacher and a small supplies budget. Other colleges and universities in Maine could duplicate these efforts, especially because highly qualified undergraduates were also successful fellows in our program.

The GK-12 STEM program demonstrated that effective partnering of university faculty, undergraduate and graduate students, K-12 teachers, and supportive K-12 administrators leads to highly successful science education from grade school to graduate school. This program provides a model for the state of Maine to increase science literacy and research capacity. 🦋

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ENDNOTES

1. These awards include some competitive renewals to the same programs; for example, each of the three successful proposals from Maine was renewed for a different time period because the rules for reapplication changed over time. Currently, NSF makes only one, five-year terminal award to successful university proposals.
2. As of August 2008, NSF's GK-12 program has involved 5,623 graduate students (fellows), 9,473 teachers, 4,732 schools and 687,594 K-12 students in the U.S. (Sonia Ortega personal communication, August 8, 2008).
3. The University of Maine Foundation provided \$2,889,558 in scholarship funding for students to the University of Maine in FY2008, but less than one percent of that funding was for graduate student support (Sarah McPartland-Good personal communication, August 8, 2008). The University of Maine through annual funding from the University of Maine System

offers a few scholarships to graduate students (Scott Delcourt personal communication, August 5, 2008), but most of these are limited to students at the beginning or end of their degree programs, which is an inappropriate time for a GK-12-like outreach activity.

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