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Teacher Preparation: One Key to Unlocking the Gate to STEM Literacy

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The American secondary school system has structural problems that are long-standing and pervasive. Too few students are engaged by their classes. Teachers can spend too little time on engrossing activities that lead to long-term learning, partly because they must spend too much time on classroom management, student preparation for high-stakes tests, and extracurricular responsibilities. The profession of teaching itself is held in low regard. Is it any wonder, then, that few college students aspire to the profession? Yet the attraction to service is strong among the current generation of undergraduates, as shown by their willingness to participate during the period immediately after earning their bachelor's degrees when offered an opportunity such as Teach for America, Peace Corps, or other structured service (Dote *et al.*, 2006; Johnson, 2011).

In the areas of science, technology, engineering, and mathematics (STEM), the need for skilled teachers is even more pronounced than in general. A large number of public school districts are understaffed in these disciplines and cannot attract highly qualified teachers. As a result, crucial elementary, middle school, and high-school STEM courses are often taught by teachers who are themselves not educated in STEM. Students of such teachers cannot help but absorb attitudes of discomfort and unfamiliarity, no matter how strong the encouragement at home. It is also less likely that parental influence can carry the day, given more than a generation of

such critical deficiencies in instruction, and a society that increasingly rejects intellectual activity as elitist and “not cool.” Even when qualified STEM graduates are attracted to the profession of teaching in public schools, they tend to leave it quickly, either for more positive rewards in other professions or to avoid the multitude of hindrances to their effectiveness as teachers (for a review, see Ingersoll and Strong, 2011). The resulting high turnover further undermines the consistent, convincing instruction that is required.

During the past decade, attention has focused increasingly on the crisis in STEM literacy throughout society. Reports appear regularly from eminent organizations pointing out the economic and social disadvantages of a technological society whose members are technologically ignorant (National Academy of Sciences, 2010; President's Council of Advisors on Science and Technology, 2012). Parents decry the quality of public school education. International comparisons of STEM achievement of 15-year-old schoolchildren leave the United States ranking low among developed countries (Organisation for Economic Co-operation and Development, 2010). Consequently, political leaders regularly call for reforms, ranging from “No Child Left Behind” (No Child Left Behind Act of 2001, 2002) to “100,000 new STEM teachers in ten years” (Triangle Coalition for Science and Technology, 2012).

What can scientists and science educators do to help reverse this situation? In the ongoing effort to improve classroom teaching of STEM in primary and secondary schools, the National Science Foundation (NSF) has played an important role. Numerous programs are devoted specifically to improving the K–12 classroom science experiences of students, using the newest information on how children learn at various stages of their development. In addition, frequent efforts are made to broaden the impact of a project not explicitly focused on education by including an outreach component involving K–12 students and/or teachers. Such enrichment, however, must be consistent and regular to have an effect. In this article we present areas in which the NSF supports efforts to improve K–12 STEM teaching and learning, and we invite your participation. We first describe a signature teacher preparation program of the foundation, the Robert Noyce Teacher Scholarship Program. We then survey other

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Table 1. Number of funded projects (1998–2011) involving teacher education

Directorate	Division ^a	Awards including teacher education
Biology	DBI	1
	DEB	3
	IOS	4
	MCB	7
Computer and Information Science and Engineering	CNS	5
Education and Human Resources	DGE	1
	DRL	83
	DUE	105 plus 350 Noyce projects
	HRD	14
Engineering	CBET	1
	CMMI	1
	ECCS	2
	EEC	4
	IIP	1
Geosciences	AGS	3
	EAR	3
	OCE	4
Mathematics and Physical Sciences	AST	1
	CHE	2
	DMR	6
	DMS	1
	PHY	1
Polar Research	ANT	2
Social, Behavioral, and Economic Science		1
Office of International Science and Engineering		1
Office of Integrative Activities		1

^aAcronyms for names of the NSF divisions are hyperlinked to each division's home page. Searching the NSF database for projects including the term "teacher education" in the abstract yielded the above data.

more general programs, focusing on primary and secondary school STEM education.

The NSF is organized as a series of directorates. Most of these deal with specific scientific research projects in the various STEM disciplines. One, Education and Human Resources (EHR), addresses research on and application of new ideas related to STEM education at all levels, both within and beyond academic institutions. Two divisions within EHR are particularly relevant to the issue of teacher preparation: the Division of Undergraduate Education (DUE) and the Division of Research on Learning in Formal and Informal Settings (DRL). Of the 608 projects funded by the NSF in the past 13 yr that reference teacher education, 88% came through either DUE or DRL (see Table 1).

A key program in this area is the Robert Noyce Teacher Scholarship Program, funded through DUE (www.nsfnoyce.org). Established by an act of Congress in 2002, the program was reauthorized in 2007 as part of the America COMPETES Act and again when that act was reauthorized in 2010. Its goal is to encourage talented STEM majors and career-changing STEM professionals to pursue teaching careers. It also provides opportunities for highly effective classroom teachers to learn the leadership skills needed to serve as master teachers. The rationale is that only a thorough familiarity with STEM content will enable a teacher to effectively engage a class

of middle or high school students in STEM learning. Colleges and universities that offer Noyce Scholarships recruit recipients from among students who have already decided to major in one of the STEM disciplines. Generous financial support (ranging from a minimum of \$10,000 per year up to the entire cost of attendance) provides the resources for students to complete their STEM major, engage in the education course work needed to qualify for a teaching credential, and embark on a teaching career. To benefit the neediest K–12 students directly, Noyce Scholars are required to teach for 2 yr in a high-need school district for every year of support they have received. A district is considered "high-need" if at least one of its schools has students from impoverished families, a high percentage of teachers teaching outside their area of expertise, or unusually high teacher turnover. The most successful Noyce Scholar programs provide not only excellent STEM experiences for their majors and effective teacher preparation, but also address the issues that are likely to arise in a high-need environment and offer ongoing support for teachers in their induction years (the first few years of independent teaching). In the 10 yr since its inception, the Robert Noyce Teacher Scholarship Program has supported a variety of models for preparing STEM teachers and has amply fulfilled its promise of producing effective and motivated STEM teachers, to the point that many school districts specifically

recruit among Noyce Scholars. The current cadre of Noyce Scholars numbers more than 5000. They were trained in programs supported by 350 awards to colleges and universities in 45 states, the District of Columbia, Puerto Rico, and the U.S. Virgin Islands. Cooperation among STEM faculty and education faculty on a variety of campuses has been a key element in developing many innovative strategies. In late May, a booklet was published by the American Association for the Advancement of Science highlighting the successes of the program in this, the tenth anniversary year (AAAS, 2012).

Many pathways lead to certification or licensure to teach in public schools, and these are determined by state departments of education. For example, in Massachusetts, a preliminary license can be obtained with a subject-appropriate bachelor's degree and passing scores on the appropriate examinations. An initial license also requires completion of a state-approved teacher preparation program. A professional license requires 3 yr of employment under an initial license, with induction and mentoring. Options for further academic enrichment include National Boards, master's degrees, and additional graduate courses in the content area. Renewal of licenses requires professional development credits earned through various workshops, seminars, or other activities (www.doe.mass.edu/Educators/e_license.html?section=k12, accessed 4 June 2012). As another example, provisional secondary certification in Arizona also requires a subject-specific bachelor's degree, passing scores on the appropriate examinations, and either completion of a teacher preparation program or 30 semester hours of education courses, including 8 h of practicum or 2 yr of full-time teaching experience at or above grade 7, plus a knowledge of the Arizona and U.S. Constitutions (www.azed.gov/educator-certification/files/2011/09/secondary-certificate.pdf, accessed 30 May 2012). In the third year of teaching the provisional certificate is converted to a standard secondary education certificate. Special requirements allow a candidate to receive an endorsement as approved to use Structured English Immersion. Teacher preparation programs (and hence Robert Noyce Scholarship programs) must conform to the regulations of the state in which the teachers will become certified, generating considerable variability in their structure. Many states, however, offer reciprocity for teachers whose credentials are earned elsewhere.

In response to teacher shortages in key areas, including STEM, many states now offer alternative certification programs (Feistritzer, 1994). These are particularly attractive to career-changers who want to become teachers. Having already demonstrated skill in their STEM profession, they now need to learn how to teach. These certification programs require less formal course work and thus shorten the time required for a person to earn teaching qualifications. Some are supported by the Robert Noyce Scholarship Program. Other alternatives include such programs as Teach for America, in which most candidates have relatively little formal teaching preparation and no student teaching experience. Other recent college graduates are attracted to teaching in private schools, in which no certification is required. While these alternatives can bring talented and knowledgeable people into the STEM classroom, studies have demonstrated that certified teachers are more effective in stimulating K–12 student learning than those without special pedagogical training (Darling-Hammond *et al.*, 2005).

In the competition for award of Noyce Scholarship projects, the NSF looks closely at the quality of the program for the STEM majors, the quality of the teacher preparation program, and the interaction between the STEM and education faculty. In many cases, the opportunity to submit proposals to the Robert Noyce Teacher Scholarship Program has stimulated or renewed conversations among education and STEM faculty who otherwise might seldom interact; such dialogue is a key component of a successful program. Also needed are strong ties to one or more local public school systems (particularly helpful if they are high-need) and other local agencies in which future teachers can find informal opportunities of benefit to their students. The school system(s) must be willing to provide student teaching opportunities and offer appropriate mentoring. Ideally, it will also welcome Noyce Scholars as employees once their preparation is complete. Local science museums, nature parks, and other informal science education sites; STEM-oriented industries; and small businesses can provide support to the program through internships and/or research opportunities that enrich the Noyce Scholars' experiences. As programs using inquiry-based, student-centered pedagogy are emphasized, both in the education of the Noyce Scholars and in their teaching preparation, real-world experiences of science in action are key for adding depth and detail to a teacher's resources.

Other programs at the NSF that can promote teacher preparation include several in DUE:

- Advanced Technology Education (ATE), which focuses on education of technicians for technology fields. Professional development of secondary school teachers can be an element of an ATE project (www.nsf.gov/funding/pgm_summ.jsp?pims_id=5464&org=DUE&from=home, accessed 27 May 2012). This program is cofunded through DUE and DRL.
- Math and Science Partnerships, which aims to raise achievement levels of K–12 students and reduce the gaps in achievement typically seen in diverse student populations (www.nsf.gov/funding/pgm_summ.jsp?pims_id=5756&org=DUE&from=home, accessed 27 May 2012). Colleges and universities form partnerships with local school districts to offer or test innovative approaches in STEM education. Teacher preparation is one of the targeted areas.
- Scholarships in STEM, which provides scholarships and support to academically talented but financially needy students to permit them to complete their STEM major (www.nsf.gov/funding/pgm_summ.jsp?pims_id=5257&org=DUE&from=home, accessed 27 May 2012). Some of these students will become teachers.

In DRL, research on learning is emphasized, and key programs include the following:

- Discovery Research K–12, which supports research proposals involving important current or anticipated needs in prekindergarten through high school education (www.nsf.gov/funding/pgm_summ.jsp?pims_id=500047&org=DRL&from=home, accessed 27 May 2012).

2012). An important strand of support is for models and tools for teacher education that have an impact on student learning.

- Innovative Technology Experiences for Students and Teachers, which seeks to find the best way to prepare students to participate in the twenty-first century workforce, focusing on K–12 students and their teachers (www.nsf.gov/funding/pgm_summ.jsp?pims_id=5467&org=DRL&from=home, accessed 27 May 2012).
- Research and Evaluation on Education in Science and Engineering, which supports research on STEM learning in all of its guises, necessarily including preparation of teachers (www.nsf.gov/funding/pgm_summ.jsp?pims_id=13667&org=DRL&from=home, accessed 27 May 2012).

In addition, NSF specifically encourages the participation of scientists in STEM education by asking that the broader impacts of a proposed research program be considered. Throughout the NSF, funded research proposals frequently include efforts to reach out to teachers and their students in the public schools. Such efforts are particularly useful if explicitly aligned to age-appropriate state standards. For example, a team at San Jose State University (Oliver, 0842064)¹ is building a database of ecosystem-wide changes in McMurdo Sound in Antarctica over the last 40 yr. An interactive website containing the data will be widely shared, and teacher education programs are explicitly included to encourage utilization in K–12 classrooms. Funded by a prestigious CAREER award, an astronomy project led by Margaret Hanson at the University of Cincinnati is developing tools to permit direct study of the birth of massive stars and includes a collaboration with the teacher education program at the university to develop a youth science program involving a series of hands-on physics projects (Hanson, 0094050). A project in Texas involving the upper Trinity River basin (including Dallas–Fort Worth) is studying aspects of the urbanized watershed that contribute to the ecological and environmental properties of the river. This project supplies data to a state-mandated environmental education program housed at the University of North Texas and works with local teachers to make the results available for their classes (Hoeinghaus, 1039172). A regional undergraduate research center in chemistry in central Virginia involves seven baccalaureate institutions, including women's colleges and those with high proportions of underrepresented groups in their student body. This project provides opportunities for participation of both preservice and in-service teachers (Granger, 0418313). A project aimed at undergraduates majoring in education offers a computer science endorsement program to ensure that graduates have had experience with computational thinking (Hoffmann, 0938999). The Laser Interferometer Gravitational-Wave Observatory Science Education Center at Southern University in Baton Rouge has formed partnerships with the departments of education, physics, mathematics, and science/mathematics education at the university; a Louisiana educational reform agency; and the San

Francisco Exploratorium to provide experiences for preservice and in-service teachers and their students at this state-of-the-art physics research facility (Meyinsee, 0917543). And many directorates support teachers conducting laboratory or field research with NSF-funded scientists in Research Experiences for Teachers. Table 1 summarizes the results of a search of the NSF databases for projects involving teacher education. Clearly, such projects are funded throughout the foundation, not only in EHR. Interested readers may find support for their ideas to strengthen teacher preparation in STEM fields within a number of programs at NSF.

With increased attention to teacher preparation and insistence on strong content mastery, we predict that student learning will improve and the pathway for students to STEM literacy and participation in the STEM workforce will be cleared. The combination of deep understanding of scientific content, high expectations for student performance, and engaging pedagogy, as epitomized by graduates of Noyce Scholar programs, is the gold standard for teacher preparation. The need is great, however, so widespread efforts on all fronts are needed to achieve the desired results. The NSF is eager to partner with you in this endeavor.

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¹ Abstracts of NSF awards may be found by searching the NSF website (<http://nsf.gov/awardsearch/>) using the project number, which begins with the last two digits of the year of the award.

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