



GEOSCIENCE EDUCATION AND DIVERSITY: VISION FOR THE FUTURE AND STRATEGIES FOR SUCCESS

REPORT OF THE SECOND GEOSCIENCE EDUCATION WORKING GROUP

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EXECUTIVE SUMMARY

More than eight years ago, a group of scientists and educators came together in a working group to discuss the need for a strong emphasis on geoscience education within the Directorate for Geosciences (GEO) at the National Science Foundation (NSF). This group outlined a set of geoscience education priorities and strategies for GEO that have served to define and guide the Directorate's education and diversity (E&D) efforts to date. Since that first working group met, remarkable progress has been made in advancing geoscience education, in large part as a result of the clear thinking and dedication that went into the conception, design and implementation of the NSF/GEO E&D programs. Nearly a decade has passed since the first report and, although many of the issues articulated by that group remain relevant, the landscape for geoscience education and science education in general has changed in response to changes in national priorities, advances in technology, progress in science education research and changing US demographics. Recognizing the need to assess the impact of GEO investments in E&D and where the community stands with respect to the goals articulated in the original working group report, NSF/GEO convened a second working group to evaluate the current status of the GEO E&D endeavor and to make recommendations for the next phase of NSF/GEO E&D activities.

The second Geoscience Education Working Group (GEWG II), meeting on October 25-27, 2004 at the National Science Foundation (NSF) in Arlington, Virginia, reviewed 4 programs managed through the office of the Assistant Director for Geosciences (GEO): Awards to Facilitate Geoscience Education (AFGE), Geoscience Education (GeoEd), Global Learning and Opportunities to Benefit the Environment (GLOBE) and Opportunities for Enhancing Diversity in the Geosciences (OEDG). The working group was charged with identifying emerging needs and opportunities related to geoscience E&D, developing new goals and standards for GEO E&D programs and recommending a future course for GEO E&D efforts. From more than two days of intense discussion and debate emerged a report that includes a discussion of the overall status of the geoscience E&D community, recommendations for how the community can best promote improvements in the geoscience education enterprise and a set of strategies for strengthening GEO E&D programs.

The GEWG II concluded that the emergence of a coherent and growing geoscience E&D community constitutes the primary strength of the geoscience education enterprise. An increasing number of prominent members of the geoscience community are advocating for geoscience education within government, industry and academia. Moreover, opportunities now exist to integrate research and education through large-scale NSF research projects. Members of the community are increasingly active in scientific professional societies and are capitalizing on the reach and breadth of these organizations to disseminate effective practices in education. Geoscience curricula are being designed to align with national priorities in research, education and workforce development, and have great potential for inspiring students to pursue geoscience-related careers. Community interest in scholarly research on E&D is growing rapidly.

Major objectives identified as beneficial to the future success of the geoscience education enterprise include: promoting and publicizing the synergy between geoscience and national priorities; increasing the breadth, scope and quality of geoscience education at all levels; and developing a more diverse geoscience community. To achieve these objectives, the community

should become more proactive in disseminating information about the geosciences to the media, teaching geoscience well and broadly in formal settings at all grade levels as well as in diverse informal settings, using education research to inform effective pedagogical practices in the geosciences, disseminating and promoting effective practices, and focusing resources on recruitment and retention of members of underrepresented groups into the geosciences.

The working group recommends that NSF/GEO enhance the impact of current programs by encouraging proposals with a high potential for success. Demonstrable, lasting impact is a key element of successful projects. Well-articulated needs, goals and objectives, a strong implementation plan and an evaluation plan that is aligned with the goals and objectives are hallmarks of proposals with high potential for success. GEO should provide easily accessible information on effective practices, exemplars or models of successful projects and assist PIs in learning about and implementing best practices.

In addition, GEO should fund an externally managed *enterprise assessment* for the geosciences to document current national needs in the geosciences, including job market trends, relations between geoscience education and national priorities, current major initiatives in geoscience education, and gaps in geoscience education and training.

Seven longer-term actions recommended by the working group include: 1) periodically evaluating the results of GEO's funded projects in order to identify best practices; 2) requiring proposers to adhere to a clearly defined set of project guidelines; 3) improving the system of project oversight, management and reporting; 4) continuing to fund development of creative new approaches in geoscience education; 5) encouraging direct involvement by professional societies in GEO funded projects; 6) promoting the inclusion of scholarly educational research in future projects; and 7) continuing efforts to integrate basic geoscience research with education.

Recognizing that a better and broader public understanding of geoscience and its significance is truly essential, and that education is the only route to achieving this goal, the first Geoscience Education Working Group paved the way for the strong and growing geoscience education community that now exists. The GEWG II has endeavored to provide guidance for building upon this excellent foundation and to define a pathway for the next decade of GEO E&D activities.

SECTION 1. INTRODUCTION

The second Geoscience Education Working Group (GEWG II) met on October 25-27, 2004 at the headquarters of the National Science Foundation (NSF) in Arlington, Virginia. The GEWG II evaluated the effectiveness of prior and ongoing geoscience E&D programs in the Directorate for Geosciences. The GEWG II also developed recommendations for the Directorate for Geosciences (GEO) at NSF regarding its programs and future funding decisions. Members of the GEWG II were invited to participate because of their unique qualifications, prior contributions in the areas of geoscience education and/or diversity enhancement in science, technology, engineering and mathematics (STEM) fields, and their potential to make a substantive contribution to the group.

The GEWG II was convened in response to the recommendations of an NSF Committee of Visitors (COV) for Education and Human Resource Development in the Directorate for Geosciences, which met at NSF headquarters on September 10-12, 2003. The COV conducted a thorough review of the Directorate for Geosciences' E&D programs. Their report is available online at:

<http://www.geo.nsf.gov/geo/adgeo/advcomm/fy2003_cov/GEO_ED_2003_COV_report.doc>.

The COV recommended that the GEWG II be convened to further examine previously funded geoscience E&D projects and guide the Directorate for Geosciences in planning for the future. The GEWG II is a Subcommittee of the NSF Directorate for Geosciences Advisory Committee.

To decrease the amount of time needed by the GEWG II to address its charge, an external contractor, the American Institutes for Research (AIR), was hired by NSF during the spring of 2004 to collect retrospective data related to four E&D programs conducted at the level of the Office of the Assistant Director for Geosciences at NSF. The four programs are: Awards to Facilitate Geoscience Education (AFGE), Geoscience Education (GeoEd), Opportunities for Enhancing Diversity in the Geosciences (OEDG) and Global Learning and Observations to Benefit the Environment (GLOBE). These programs are broadly representative of the entire suite of E&D related programs and projects conducted by GEO. The Digital Library for Earth System Education (DLESE) Program Center and Core Services were not specifically analyzed by the GEWG II, but the GEWG II was encouraged to make recommendations related to DLESE as appropriate.

The official charge to the GEWG II:

1. Using summary materials provided by NSF and its contractor, assess accomplishments of the Awards to Facilitate Geoscience Education, Geoscience Education, Opportunities to Enhance Diversity in the Geosciences and GLOBE programs since 1996.
2. Collaborate with members of the NSF Geoscience Education Team (GET) to accomplish the following tasks:
 - Identify emerging needs and opportunities related to geoscience E&D.
 - Develop new goals and standards for GEO E&D programs.
 - Recommend the future course for GEO E&D programs.
 - Prepare a report.

The members of the GEWG II agreed that the overall state of geoscience E&D has significantly improved since the time that the first Geoscience Education Working Group met at NSF on August 29-30, 1996. One of the most significant accomplishments of the first Geoscience Education Working Group was its report (*Geoscience Education: A Recommended Strategy*, NSF 97-171), which led to development of a community of geoscientists dedicated to promoting and improving E&D. The report is available online at:

<<http://www.nsf.gov/pubs/1997/nsf97171/nsf97171.htm>>.

The members of the GEWG II hope that their current report will contribute to continued growth and strengthening of the geoscience E&D community in the future. The GEWG II members anticipate that a third Geoscience Education Working Group will be convened in the future.

SECTION 2. STATUS OF THE GEOSCIENCE EDUCATION AND DIVERSITY COMMUNITY

As part of the effort to address the charge to the committee, the members of the GEWG II analyzed the current state of the geoscience E&D community in terms of current strengths on which to build, current weaknesses that need to be addressed in the future, opportunities for future growth and improvement, and existing or potential threats. A summary of this discussion is outlined in Exhibits 2.1., 2.2., 2.3. and 2.4. of this section.

The primary strengths of the geoscience E&D community are its growing size and its diverse, knowledgeable and dedicated members (Exhibit 2.1). The geosciences are relevant, intriguing and integrative. The geosciences provide context and concrete examples of the application of concepts and skills from all of the STEM disciplines. NSF is perceived by the geoscience community at large as willing to facilitate continued growth and improvement in efforts to advance geoscience education and increase diversity in the geosciences.

Exhibit 2.1. Current strengths of the geoscience education and diversity community. (Information is not presented in prioritized order)

• Wide variety of interests and specialties among geoscientists concerned with E&D.
• Strong and growing community of geoscience E&D researchers.
• Sufficient proposal pressure in geoscience E&D programs.
• Fascinating and relevant subject matter that is integrative. Geoscience is a good content area for delivering content and meaning (relevance) in all STEM disciplines.
• Existence of high-quality “best-practice” models.
• Broader impacts review criterion emphasizes the importance of E&D.
• Geoscientists in prominent positions in government, industry and the academy are advocating for inclusion of geoscience in curricula at all educational levels.
• NSF Geoscience Program Managers make an exceptional effort at cross-divisional and cross-directorate relationships that result in effective collaborations.
• Geoscience has promoted itself well within the STEM community. STEM experts now recognize that STEM is more than just physics, chemistry and biology.

The critical current weaknesses identified by the GEWG II (Exhibit 2.2) stem mainly from a need for coordination and collaboration within the geoscience community at large. Best practices in pedagogy, including methods developed for use in large, introductory-level courses, need to be identified, communicated and implemented broadly. Geoscience is a fascinating topic that can be perceived as boring and irrelevant if it is not presented in an effective way. Geoscience curricula at all educational levels need to embrace the Earth system science approach. Workforce skills need to be emphasized, including (but not limited to) quantitative expertise, the ability to communicate complex information in writing and verbally and the ability to work on interdisciplinary teams. The need for sufficient numbers of highly qualified Earth Science teachers in the K-12 workforce is a problem that has contributed to a lack of awareness of, and interest in, the geosciences among students. Perhaps even more importantly, there is a noticeable lack of diversity among practicing geoscientists, as well as NSF Principal

Investigators (PIs), reviewers and panelists, which limits the geosciences' ability to effectively engage major segments of the US population.

Exhibit 2.2. Current weaknesses of the geoscience education and diversity community.
(Information is not presented in prioritized order)

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| • Low-level of racial/ethnic and gender diversity among geoscientists, including NSF PIs, reviewers and panelists. |
| • A need for accountability for funded projects. |
| • A need for much greater community college participation (0.5% of applicants are from community colleges). PIs from minority serving institutions (MSIs) and PIs drawn from the pool of senior research faculty are also poorly represented. |
| • A need for more effective public outreach and communication to promote the geosciences as exciting and relevant. |
| • A need for effective mechanisms for dissemination/recognition of best-practice models. |
| • Quantitative skills, soft (writing and speaking) skills and teaming skills are not currently well integrated into most geoscience curricula. These skills are needed in the workforce. |
| • A need for up-to-date pedagogy at four-year universities (and other institutions). Although financial considerations typically dictate class-sizes, effective teaching strategies need to be implemented in all classes so that future geoscientists are more likely to be attracted to and retained in the discipline. |
| • A need for knowledge or broad awareness about best practices related to E&D. |
| • A need for a large number of well-trained K-12 Earth science teachers. |

There are currently numerous opportunities available to the geoscience E&D community (Exhibit 2.3). At K-12 levels, high-stakes testing in multiple grades should lead to increased emphasis on the quality of teaching and learning of science in pre-college settings. Because the geosciences focus on application of concepts and techniques from the other sciences to problems related to the Earth and the environment, the geosciences can provide nearly unlimited real-world, hands-on and inquiry-based opportunities for enhanced learning in a variety of disciplines. Effective dissemination of geoscience curriculum products can help the geosciences become more effective at drawing students into the field from other related disciplines. Venues for dissemination (e.g., DLESE) already exist and are available for use by all geoscientists. Information about careers in the geosciences also needs to be made widely available. Geoscience-related careers include opportunities in K-12 teaching; there is a critical and ongoing need for high-quality K-12 Earth science teachers. Information about best practices in teaching and ways in which fundamental concepts can be taught within an Earth system science framework should be disseminated widely using as many venues as possible.

NSF has the opportunity to use existing programs to further its efforts to enhance education and increase diversity in the geosciences. Large-scale projects should provide opportunities for students and educators to participate in research and develop programs and products that fill gaps. The NSF CAREER Program should be used as a vehicle to highlight the potential of promising new geoscience faculty within their home institutions and ensure that best practices in education are broadly implemented. PIs who are typically involved in basic research have the

opportunity to learn more about E&D when they work with experts from the E&D community to develop education and outreach programs.

Exhibit 2.3. Opportunities for future growth and improvement of the geoscience education and diversity community. (Information is not presented in prioritized order)

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| <ul style="list-style-type: none">• Geoscience researchers (especially those associated with new or emerging NSF research centers) have the opportunity to learn more about effective educational practices as they conduct education and outreach activities. |
| <ul style="list-style-type: none">• Inclusion of science testing at high, middle and elementary school levels (grades 4, 8 and 10) provides an opportunity for geoscience to reach more students. |
| <ul style="list-style-type: none">• CAREER can be used as a vehicle to involve additional new PIs in geoscience education efforts. For this to occur, reviewers need to be educated to recognize that “innovative” education plans can either use new approaches or apply existing best practices in a new setting. |
| <ul style="list-style-type: none">• The geosciences have the potential to form interdisciplinary teams with other disciplines as departmental reorganizations occur. |
| <ul style="list-style-type: none">• The number of talks and poster presentations related to education is rapidly growing at national geoscience meetings. There is an opportunity to undertake nationwide reform of geoscience education because a critical mass of concerned educators is emerging. |
| <ul style="list-style-type: none">• Information about workforce needs and careers can be used to effectively recruit students into the discipline. |
| <ul style="list-style-type: none">• Highly qualified Earth science teachers are in demand at the K-12 level. Additionally, the impending retirement of senior faculty may result in new positions at post-secondary institutions. |
| <ul style="list-style-type: none">• Large-scale NSF research projects offer a plethora of opportunities to integrate geoscience research and education. These projects should provide opportunities for undergraduates and educators (particularly from low-income or underrepresented populations) to participate in research. Educational products (e.g., curricula) produced by the projects should be developed to address gaps in current educational materials and made available to the community at large. |
| <ul style="list-style-type: none">• Special sessions, special issues of journals related to geoscience education, workshops at NSF and in conjunction with society meetings, and the world-wide-web can be used to disseminate best-practice information to the geoscience community. |
| <ul style="list-style-type: none">• Align curriculum with national priorities to increase impact and perceived importance of geosciences. |
| <ul style="list-style-type: none">• Earth system science approaches to teaching geoscience are ideal for integrating quantitative, soft (writing and speaking) and teaming skills into curricula. |

Most of the threats to the geoscience E&D community relate to the need for increased recognition of the importance of geoscience E&D programs to the long-term health of the geoscience enterprise (Exhibit 2.4). Many geoscientists involved in basic research are uninformed about the critical role that high-quality educational practices, tailored to meet the needs of diverse groups, can play in advancing student and public understanding of geoscience research. While NSF and other funding agencies have made enormous strides over the past 10 years, the GEWG II felt that there needs to be continued and increased emphasis on E&D when

funding decisions are made by NSF and other federal agencies. Professional societies should take a more proactive role by uniting their memberships to work together to improve the quality of geoscience education and increase diversity in the geosciences.

Exhibit 2.4. Existing or potential threats to the health of the geoscience education and diversity community. (Information is not presented in prioritized order)

- There is a need for awareness within geoscience research community that education-related projects are fundamentally important to the health of the geoscience enterprise.
- There is a need for increased recognition of geoscience education as an important emerging field of research by the geoscience community at large and by the scientific societies.
- There is a need for sufficient financial support for geoscience education projects within the Directorate for Geosciences and NSF as a whole. The Divisions of GEO should promote geoscience education by consistently stressing the importance of the broader impacts criteria to PIs, reviewers and panelists.
- Declining enrollments in geoscience disciplines continues to threaten the overall health and productivity of the discipline. Geoscience may suffer from a loss of identity due to closing and merging of geoscience departments in the future.
- Employers are looking to non-US citizens to supply needed skills to the workforce rather than work with the US educational system to improve the skills of US citizens.

In summary, the current strengths and opportunities of the geoscience E&D community are numerous and should be acted upon to promote the future health of the geoscience research enterprise.

SECTION 3. VISION FOR THE FUTURE: RECOMMENDATIONS FOR THE COMMUNITY AT LARGE

The continued growth and improvement in the geoscience E&D enterprise depends in large part on community-wide actions. Reflecting on the discussion of the current status of geoscience education, the GEWG II articulated four major issues perceived as critical to the future vitality of the community:

1. Promoting and publicizing the synergy between geoscience education and national priorities;
2. Increasing the breadth, scope and quality of geoscience education at all levels;
3. Developing a vibrant, diverse, innovative geoscience community; and
4. Regularly assessing and expanding community-wide goals if necessary.

Although these issues have bearing on how NSF/GEO promotes and supports community-wide efforts, they are most appropriately characterized as issues that will require community-based action to promote systemic change within the community at large.

3.1. Promoting and Publicizing the Synergy Between Geoscience Education and National Priorities

Alignment with national research and development and STEM education priorities is essential to the long-term success of geoscience education enterprise. That the geosciences are widely applicable to problems of national interest is one of the key strengths of our community and should serve as the cornerstone of efforts to promote the importance and relevance of geosciences to the public. Key priority areas that can be addressed by geoscientists include:

- Strengthening science, technology, engineering and mathematics education
- Supporting technological innovation to enhance economic competitiveness and new job growth
- Addressing national workforce needs to ensure a scientifically literate population and a robust supply of qualified experts
- Advancing fundamental discovery to improve quality of life in the future
- Enhancing our understanding the global environment

Professional societies such as the American Geophysical Union (AGU) have begun exploiting a variety of avenues for “getting the message out” about important contributions that the geoscience community is making to national safety, health and prosperity. Publications, press releases, media events and public service announcements all present opportunities for highlighting the importance of the geosciences in addressing national priorities. A clear and understandable message about the value and importance of the geosciences must be created and marketed effectively. To this end, members of the geoscience community should generate a greater media presence either through cooperative efforts with NSF and other federal agencies, professional societies or on their own.

Education has always been vital to the success of the science and engineering enterprise. In the technology- and knowledge-based economy of the 21st century, STEM education is an investment in the United States collective future as a nation and as a society. The geoscience community has a pivotal role to play in the pursuit of the nation's STEM education goals. Key opportunities exist because geoscience provides context for chemistry, physics and biology and solutions to many of the economic and environmental challenges facing the nation. The geoscience community needs to work collectively to promote geoscience as a vehicle for strengthening STEM education and for attracting students to STEM careers.

For lasting systemic change to take place, policy changes must be enacted at the district, state and national levels. The geoscience community should encourage projects or initiatives that establish communication with entities that make or guide policy decisions, focus on communicating the importance of geoscience to various constituent groups, or develop aligned geoscience curricula. Consortia that include education-oriented and geoscience-oriented¹ professional societies will be most effective in promoting systemic change. Entities such as NSF, the Office of Naval Research (ONR), the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), the United States Geological Survey (USGS) and geoscience-oriented professional societies need to partner in a coordinated effort to promote the inclusion of geoscience content in K-12 education.

3.2. Increasing the Breadth, Scope and Quality of Geoscience Education at All Levels

Quality and breadth constitute important pillars of geoscience education programs. Geoscience must be taught well and broadly, in formal settings at all grade levels, as well as in diverse informal settings including science centers, museums, parks and via the Internet. The geoscience education community needs to continue to perform education research and to avail itself of the results of educational research conducted in other STEM fields. There is a continuing need to identify and promote pedagogical approaches that work and to communicate information about why some approaches work while others do not. As evaluation becomes an increasingly prominent component of geoscience education projects, greater numbers of geoscience educators will be able to identify and disseminate information about effective pedagogy.

As effective practices are identified, the geoscience community needs to work together as a team to overhaul geoscience education. Improvements in geoscience education that result from coherent, coordinated efforts will benefit the entire community. Improved educational practices at all grade levels will contribute to increased competency among future researchers. Geoscience

¹ Examples of some of these organizations include: the Association for Supervision and Curriculum Development <[www.ASCD.org](http://www.ascd.org)>, International Society for Technology in Education <www.iste.org>, National Association of Elementary School Principals <www.naesp.org>, National Education Association <www.nea.org>, National Association of Elementary School Principals <www.naesp.org> and the Council of Great City Schools <<http://www.cgcs.org>>.

professional societies can provide leadership and assistance in many ways and their participation must be a key component of any plan to implement systemic change.

Relevant and exciting presentations within informal education venues will lead to improved understanding and appreciation of the natural world among the general public. The growing number of partnerships between the geoscience research community and informal science educators should be used to disseminate up-to-date geoscience information to the general public.

Many of the issues facing the geosciences are impacting other STEM disciplines as well. There must be effective communication and collaboration among all disciplines (e.g., physics, chemistry, etc.) and relevant stakeholders (e.g., employers, funding agencies, government, etc.) involved in the STEM enterprise to ensure that a strong science and engineering workforce continues to exist. Geoscience applications provide context and concrete meaning that can be exploited by educators in other disciplines. Geoscience educators (particularly those involved with the K-12 system and/or teacher training) should collaborate with colleagues in other disciplines to incorporate geoscience examples throughout STEM curricula. The integration and inclusion of geoscience into a wide variety of STEM courses at the pre-college level must be encouraged.

Members of the community need to be proactive in seeking out opportunities for expanding the reach of geoscience curricula (for example, into other university departments). While care should be taken to preserve the identity of the geosciences, it is imperative that the community embrace opportunities for inclusion in interdisciplinary programs. Geoscience research is becoming increasingly dependent on technologic innovations and students who wish to perform geoscience research need to have strong quantitative skills. The use of geoscience examples in mathematics education would benefit both the geoscience and mathematics communities. Applications of quantitative skills should be emphasized at all levels of geoscience education.

The typical undergraduate geoscience curriculum does not match the needs of industry and academia. Students entering the workforce don't have sufficient quantitative preparation, a sufficiently robust Earth system perspective, or essential soft skills. Three alarming trends are evident. First, at many colleges and universities across the country, geoscience departments are decreasing in size and in some cases being eliminated altogether. Second, industry is increasingly looking to other countries to meet their workforce needs. Third, the technical complexity of problems being addressed in the commercial and mainstream research environment is increasing, while undergraduate programs in general do little to prepare students to deal with such complexity. The geoscience community must work together to develop ways to mitigate these trends. Industry representatives are increasingly interested in finding individuals that have a broad, interdisciplinary technical focus, combined with the ability to work as a member of a team. Unfortunately such students are becoming hard to find in the U.S. and the quantitative skills of U.S. students fall short of those possessed by students who were trained in other countries.

The requirement that all proposals to the NSF explicitly articulate the *broader impacts* (i.e. communication of the findings and methods of research in a **broader** context and to a larger audience) of the project has been very effective in raising the research community's awareness of

the importance of E&D. Universities should implement similar criteria in their evaluations of faculty, administrators and programs. Positive outcomes should be rewarded appropriately. Employers and/or professional societies could benefit from including a modified ‘broader impacts’ criterion during external reviews or when developing rankings.

3.3. Developing a Vibrant, Diverse, Innovative, Geoscience Community

To promote future development of a vibrant, diverse, innovative geoscience community, including researchers, educators, students, employers, policymakers and interested individuals among the general public, geoscience must be broadly perceived as important and relevant. Members of the geoscience community must therefore be more proactive in disseminating information about the geosciences to the media². An effort to promote geosciences in the media could be tremendously efficacious in enhancing the geosciences’ ability to recruit members of underrepresented groups.

Members of groups that are underrepresented in all STEM fields need to become foci of recruiting and retention efforts conducted by formal and informal geoscience educators and businesses that employ geoscientists. Members of underrepresented groups are an untapped resource for the geosciences; increased participation by diverse segments of the population will lead to increases in enrollment in formal geoscience education programs. Engineering has been more successful than the geosciences at recruiting and retaining members of underrepresented groups in part because the population at large views an engineering education as a pathway to high-paying, rewarding, white-collar employment. Broad promotion of career opportunities in the geosciences would help with recruiting efforts. Geoscientists need to use a variety of marketing techniques to demonstrate to students that careers in geoscience are exciting, relevant, challenging and available. If the community can successfully elevate public awareness of the importance of the geosciences, geoscience careers will emerge as viable career options that will directly benefit society. Representatives from the business community could take a leadership role in this effort by featuring geoscientists in their company’s promotional materials.

Recruiting of students needs to take place at the local, regional and national level. The effort to recruit students should begin early (at the elementary level, including promoting awareness of the geosciences among families and communities) and continue through the secondary, undergraduate and graduate levels. Explicit involvement of geoscience employment sectors will be required if efforts at broadening participation are to be successful. Opportunities for internships and research experiences should ideally be made available to all students.

² For example, the Shifting Baselines public outreach approach is very effective at communicating science information to the general public (see: <www.shiftingbaselines.org>).

3.4. Expanding Community Goals

Standing major goals for the community based on two major reports are outlined below.

- Goals from *Geoscience Education: A Recommended Strategy*:
 - Increase numbers of women and minorities in the geosciences
 - Improve content-area preparation for K-12 teachers
 - Update undergraduate courses and programs
 - Prepare graduate students broadly to ensure their flexibility in the future
 - Reward faculty at colleges and universities for teaching excellence
 - Educate the public about geoscience.
- Goals from *Revolution in Earth & Space Science Education*:
 - Increase the number of students learning about Earth and space science at K-12 levels and the amount of time spent on Earth and space science in K-12 curricula
 - Increase the diversity of geoscientists
 - Develop science-literate citizenry.

These goals continue to be appropriate. To remain effective, however, the geoscience education community must respond to an ever-changing national landscape and additional community goals must be embraced. The GEWG II suggests the following additional goals:

1. Improve preparation of students so that they have the skills to enter and compete successfully in the workforce. Students need to possess the following:
 - Strong quantitative skills
 - Ability to work on interdisciplinary teams
 - An Earth systems perspective
 - The ability to communicate complex information to many types of audiences, using multiple tools and methods.
2. Implement the use of an Earth system science perspective in education at all levels.
 - Train a cadre of Earth science teacher professionals to use Earth system science as a framework for instruction (K-12, college and university levels).
3. Inspire students to enter the geoscience profession.
 - Emphasize challenges and opportunities open to highly trained, technologically savvy geoscientists
 - Develop networks to help students find satisfying employment upon graduation.
4. Revise, as a community, the duration and structure of undergraduate geoscience programs.

SECTION 4. STRATEGIES FOR SUCCESS: RECOMMENDATIONS FOR NSF GEOSCIENCES

In the interest of building on the excellent foundation that now exists for geoscience E&D at NSF/GEO, the working group endeavored to define a set of strategies that can be used by the directorate to enhance and expand the impact of the programs it currently sponsors. The recommendations fall into two broad categories: 1) general suggestions for encouraging proposals with a high potential for success and 2) a set of specific recommendations for future E&D activities within the Directorate.

4.1. Characteristics of Successful Projects in Geoscience Education—Models for Success

Demonstrable lasting impact is a key element of successful projects. Impact is typically gauged based on the size of the group affected, but a focused effort that dramatically improves performance for a few individuals is also important. While there are many approaches and strategies that lead to success, projects are most likely to be successful if they have well articulated needs, goals, objectives, a strong implementation plan and an evaluation plan that is aligned with the goals and objectives. The effective use of formative and summative evaluation is the hallmark of successful projects.

Two strategies that are particularly common in successful projects deserve special mention: making use of information gained during prior projects conducted by the PIs or others and making use of partnerships. Education projects, like research projects, must make use of the most up-to-date information available during project design phases. Partnerships should be well developed and truly collaborative. Real partners share resources, governance and decision-making responsibilities. University researchers involved in K-12 education should collaborate with K-12 teachers and administrators to fully understand K-12 education issues.

4.2. Criteria for Identifying Potentially Successful Projects

Proposals should include data and rationale that indicate need and identify the specific audience to be targeted. Goals and objectives for individual projects should be few in number, but clearly stated. Progress toward stated goals and objectives must be measurable by quantitative or qualitative means. A well-articulated evaluation plan that is aligned with the project's goals must be included with each proposal. Project evaluation plans should include a rigorous research design appropriate to the type of project. Evaluation data should form the foundation of any proposal requesting a continuation of funding from NSF or any other agency.

Proposals should include an implementation plan with timelines and benchmarks that are tied to the project's objectives. Proposals to work with a specific target population must include evidence of strong partnership, with members of that target population actively involved in the planning, implementation and governance of the project.

Proposals should include a plan for dissemination of results. The dissemination plan should reach out to the largest possible audience for which the results may be important. PIs should consider multiple avenues for dissemination. A successful dissemination plan provides venues and opportunities for a wide audience to learn and potentially adapt or adopt the project's products for their own use. Workshops can play a particularly important role in dissemination.

4.3. The Role of GEO in Encouraging Development of Projects with High Potential for Success

Effective projects in geoscience education adhere to the same standards of excellence as quality research endeavors. Knowledge of pertinent literature, sound theoretical design and implementation driven by best practices are touchstones of high-caliber activities. Inquiry-based, authentic instruction supported by the use of appropriate technology is typically a part of a quality geoscience education project.

By emphasizing the characteristics of successful projects in Program Solicitations, NSF can encourage adoption of best practices. The following information should be included in Geoscience Education Program announcements:

- Exemplars demonstrating broad impacts of GEO projects as well as successful project management, evaluation and dissemination plans
- Links to tutorials that showcase successful grant writing tips
- Information to support the transition from GEO E&D funding to funding from the NSF Directorate for Education and Human Resources (EHR) and other funding agencies.

NSF should give preference to proposals that show evidence of meaningful collaboration with professional societies. These partnerships ensure that an initiative will have a high degree of sustainability as well as wide professional recognition and community involvement.

There is a need for mentoring of proposal writers in all venues, including PIs from underrepresented groups. NSF should have a white paper on the GEO website describing the types of activities that can satisfy the broader impacts review criterion.

Annual reports are an important management tool for both the PI and NSF. NSF should pay attention to the impact of its programs by requiring sections in the annual report devoted to both the intellectual merit and the broader impacts of each project. Final reports are valuable to NSF in identifying and disseminating information about successful projects as well as identifying best practices. At present the final report form is not well designed for showcasing the outcomes of projects or identifying lessons learned. It may be that a customized set of reporting questions is required for educational projects (as is done in EHR). NSF should consider how final reports could be made more effective as vehicles to promote dissemination.

The working group believes that PIs do not understand the importance of reports and how NSF uses PI's information for its own internal reports. Reporting instructions should be provided to

PIs to stress the importance of submitting thorough annual and final reports. There is an important role for NSF to play in assisting with dissemination of effective practices. The world-wide-web is a natural tool for organizing digital products and materials. An extension to the reporting system promoting use of DLESE or some other site could be a powerful tool to help promote a culture of reuse rather than reinvention.

All education efforts within the Directorate should unify behind broad goals that are aligned with workforce goals. Industry perceives students as lacking quantitative skills. Today's students must also possess qualitative skills such as working in culturally diverse teams. To allow our students to remain competitive with the global workforce, development of effective teaching strategies that strengthen these skills should be encouraged.

There needs to be a standard approach to data collection that can be used by all PIs and NSF Program Officers to critically evaluate projects. Evaluation results should be used to refine ongoing projects and design new projects. Program Solicitations should guide PIs' development of evaluation plans. The PI should be encouraged to continually communicate with the evaluator, seeking formative feedback to inform potential revisions in the implementation plan. Evaluation data must be included in the annual and final project reports to NSF. Final project reports must include a final evaluation report that documents project performance relative to original objectives. Evaluation data are necessary for identification of best practices and for determination of the collective impact of GEO education programs. PIs may need assistance to effectively incorporate evaluation into their projects. NSF should provide this assistance.

To assist overburdened faculty members, the results of NSF-funded geoscience E&D projects that involved development of new courses, curricula, or other educational materials should be shared with the community. Ideally, new materials will be made available for testing and previously tested materials will be made available for broad implementation. This would increase the impact of GEO's investment in geoscience education. Furthermore, GEO needs to develop tutorials and examples that will assist PIs in planning and developing transitions from proof-of-concept to full-scale educational projects. GEO PIs also need information about other potential sources of funding (e.g., EHR).

GEO needs to facilitate the geoscience community's understanding of the 'Broader Impacts' criterion. NSF Program Officers need to ensure that the potential broader impacts of projects are fully addressed in proposals, as well as annual and final reports. Information about new opportunities, priorities and focus areas need to be widely shared with the community. DLESE may be an ideal place for dissemination of information to prospective PIs.

4.4. Issues for Specific Target Populations

Grades K-8

At primary grades geoscience content should be incorporated into math and reading instructional materials. Projects that support development of geoscience-specific activities and develop young children's understanding of Earth systems should be encouraged. Some examples of potentially

effective practices include: alignment of children's literature with geoscience-related activities; development of a standards-based scaffold for geoscience concepts for preschool through grade six; and dissemination of kits and web-based resources for teachers.

Non-science teachers can support the geosciences through interdisciplinary instruction in which the geosciences play a prominent role. Professional societies should be partners in the development of content-rich interdisciplinary instruction.

Grades 9-12

Efforts should be made to provide students and teachers with authentic research experiences that make use of appropriate technology. Classroom activities and materials should be aligned with National and/or State Standards. The working group felt that place-based instruction could be an especially important catalyst for minority student participation and success.

Geoscience teachers need opportunities to gain content-area knowledge so that they have the confidence to make changes in their lessons, going beyond the facts given in textbooks. Teachers should be shown how to integrate math and language arts into a science lesson. The end result will be richer instruction for their students.

There are substantial research data on characteristics of high quality professional development for K-12 science teachers. Critical best practices include: addressing state standards, sustaining professional development over sufficient time to allow for complete integration of new skills and developing strategic partnerships to provide for follow-up and sustainability. Multi-level mentoring can provide the extra support that teachers need in their classrooms. Teachers should be introduced to the geoscience professional organizations in their area. Projects targeting teachers should utilize previously identified best practices. Exemplar models that illustrate best practices in teaching and learning in the geosciences at all grade levels and with all types of audiences should be promoted (e.g., via DLESE).

Undergraduate Education

Geoscience is an excellent platform for presenting context and meaning for physics, chemistry, mathematics and engineering at the undergraduate level. In the past, GEO has supported a broad range of projects targeting undergraduates. As a group, these projects lacked coherency, other than a continuous and growing emphasis on pre-service teacher training. Progress has, however, been achieved in student learning because of development of new courses and degree programs and updating of existing degree programs. The use of financial incentives and multiple interventions has also increased and these have been effective in attracting, engaging and retaining students.

Unfortunately, the progress made has not produced a significant increase in the number of undergraduates pursuing majors in the geosciences. The geosciences have problems recruiting students due to the perception that the field is not relevant and that it offers few career options. This perception must be changed among the general population if issues pertinent to undergraduate education are to be addressed.

Graduate Education and Faculty Professional Development

Very few projects reviewed by the working group had faculty and/or graduate students as the primary target audience even though these groups play an important role in the development and dissemination of high-quality geoscience education materials. Projects that support faculty in their professional growth contribute to the intellectual base of geoscience education. The GLOBE Program in particular has had a major impact on faculty and graduate students by providing an opportunity to mentor and work closely with K-12 teachers and students. NSF should encourage faculty to play an important role in workforce development and in increasing understanding of geoscience among the general public.

There should be efforts made to provide grant-writing workshops for K-12 and community college teachers during their own professional association meetings. NSF currently underserves these groups. The grant writing workshops should help teachers understand that they can apply for grants, can be partners in basic research projects and can serve as peer mentors for one another.

Informal Education and Public Outreach

Far too few proposals come from the informal science education community. Feedback from working group members representing this community indicates that some informal education centers would have to change their mission and goals to focus on geoscience. Informal science contributes to the general public's geoscience literacy. Informal science venues can be very effective in promoting interest in geoscience among diverse populations.

Adult Education/Literacy Programs

An enormous pool of eager learners exists within adult education and literacy programs. This audience has remained largely untapped by the geoscience education community. Geoscience topics and information can be readily incorporated into adult literacy program materials. Another target audience includes adult learners seeking vocational training, often as a means of changing careers. Many technical and engineering fields of study require a knowledge of, or even expertise in, one or more geoscience disciplines.

4.5. Future Actions for the Directorate for Geosciences

As a result of the Second Geoscience Education Working Group process, it is recommended that one immediate and seven longer-term actions be taken by GEO in support of the vision outlined above.

As soon as possible, GEO should fund an externally managed *enterprise assessment* for the geosciences that will define and document the current national context for geoscience education. Four specific areas for quantitative and qualitative assessment are identified below. GEO may opt to measure other indicators as well.

- What current job market needs and opportunities are relevant to geoscientists?
- What is the current relationship between the goals and practices of geoscience research and education, and national scientific, technological, educational, social, economic and defense priorities?
- What major efforts to improve geoscience education are currently underway and how do they relate to one another?
- Where are the gaps in geoscience education and training and which gaps need to be addressed in the short and long terms?

The results of the enterprise assessment should be accounted for in the following longer-term actions:

- GEO should consistently evaluate the results of its funded projects in order to identify best practices. This can be done proactively by:
 - Embedding specific evaluation metrics into project reporting requirements
 - Clearly identifying evaluation metrics in program announcements
 - Requiring all investigators to perform formative and summative evaluations and include evaluation reports in annual and final reports to NSF
 - Working to improve the online project report system to support meaningful reporting.
- GEO should provide examples of strong education projects to the community. Additionally, examples of types of projects that are not appropriate for support will be valuable to the geoscience community if explanations of undesirable characteristics are included.
- GEO should require proposers to clearly define and thoroughly describe the scientific and educational objectives, action plan, evaluation plan and deliverables for each proposed project.
- GEO should improve its system of project oversight, management and reporting. In particular, online communication and reporting should become simpler and more intuitive for PIs; the progress of projects (as defined by their research or teaching objectives) throughout their funding periods should be tracked more closely; and project reports should be made more useful and accessible for dissemination and programmatic assessment.
- GEO should continue to do what it has been doing well: funding development of creative new approaches in geoscience education.
- GEO should encourage direct involvement by professional societies in projects, especially for the purpose of dissemination of best practices. Professional societies are uniquely positioned to advocate for and sustain innovative approaches and actions within the global geoscience community.
- GEO should write and publish on the GEO website an aligned white paper about how the geoscience community can address the NSF *broader impacts* criterion with strategic education-related activities.

Recommendations for Specific GEO Programs

GLOBE: Although GLOBE has global recognition and a well-developed infrastructure (which should be preserved), it has not been successful at advancing geoscience research due to poor data quality and preparation of few peer-reviewed publications. The program also appears to have stopped growing. Recently, addition of new teachers and students has been offset by loss of existing teachers and students. Data from recent DLESE workshops indicate that teachers are often unable to comply with data collection protocols, suggesting that protocols need to be subjected to greater amounts of testing and evaluation prior to implementation. Recognizing that any change to the GLOBE structure will impact a broad group of stakeholders outside of GEO, we recommend that either the success criteria for GLOBE be modified, or GEO reduce or curtail its support for the program. Potential modifications to the specified criteria for success of GLOBE projects include:

- Projects should not focus on ‘rigid’ data collection protocols but rather be open to accommodating new potential collaborations. GLOBE should be a broad pathway between the classroom and the scientific community that can be used to promote participation by scientists from across GEO who have developed educational approaches of proven effectiveness.
- GEO should facilitate a modification of the GLOBE Program so that it can eventually serve as a “clearing house” for data and educational materials produced by large GEO-funded projects.
- GLOBE materials and support structures should be disseminated broadly.
- GLOBE scientists and teachers should develop easy-to-use tools to facilitate dissemination of GLOBE protocols and data.
- GLOBE projects should emphasize high-quality learning experiences. Hypotheses, experimental designs, data collection protocols, analyses and scientific conclusions should all be aligned with the National Science Education Standards.
- GLOBE projects should include rigorous formative and summative evaluations. Evaluation reports should be required components of annual and final reports to NSF. NSF should investigate the feasibility of developing a standard reporting structure for all projects supported by the GLOBE Program.

GeoEd: This program should fund innovative projects that can potentially be scaled up or replicated on a large or national scale. Proposals should clearly articulate the proposers’ long-term (beyond the GeoEd funding period) goals for the project, identify a timeline and action plan that are aligned with the long-term goals and specify milestones that must be achieved to attain the long-term goals. Proposals should also describe how projects would contribute to the overall enhancement of geoscience education. In summary, this program should support only proposals that communicate a vision that is consistent with the overall goals of the geoscience education community. All GeoEd projects must include evaluation components. The scale of the evaluation should match the scale of the project. Ideally, an individual or group other than the one that is developing the educational product should conduct the evaluation. GeoEd awards should not exceed a maximum of approximately \$100,000/year. Proposers should be encouraged to link with projects supported by other funding sources whenever possible, to maximize the impact of the funding provided by GEO.

OEDG: The two-track approach being used in this program is appropriate and should be preserved. For Track 2 OEDG awards, the Louis Stokes Alliances for Minority Participation (LSAMP) program may provide a good model for success. As indicated in the OEDG Program solicitation, OEDG projects should align with existing LSAMP structures to leverage resources wherever possible. As currently indicated in the solicitation, OEDG awardees should continue to be encouraged to take a longitudinal approach to increasing diversity in the geosciences. Awardees should continually look for ways to link their projects with other efforts to leverage resources and increase the number of opportunities for participants.

Distribution of Funds

GEO is able to commit a fairly limited amount funds to support projects related to geoscience E&D. The working group feels that the goals and interests of the geoscience education community are still maturing and undergoing rapid change. At the time the first Geoscience Education Working Group was convened in 1996, a true community of geoscience education professionals did not exist. One of the greatest achievements of GEO during the last decade has been to nurture and help the geoscience education community develop its own identity. During the next decade, the geoscience education community will be best served if NSF continues to allow for maximum flexibility in its funding portfolio. The working group recommends that GEO create and maintain a balanced portfolio of projects that fall into one of two categories:

- Experimental, innovative projects that may lead to creation of new exemplars
- Implementation projects that will put proven approaches into practice in new settings.

Overall funding for each of the two categories should be approximately equal. Projects in both categories should address one or more of the recognized weaknesses in current geoscience education: lack of emphasis on quantitative skills, lack of information about careers and lack of appreciation of the relevance of geoscience in modern society. Funding high-risk projects should be emphasized under the GeoEd Program. A mixture of high-risk and proven approaches should be supported by the GLOBE and OEDG Programs. Projects supported by GEO should be designed so that the GEO support can be used to leverage future funding from other sources, or promote full integration of the award activity into the normal course of business at the awardees' sites.

Durations of projects are controlled primarily by their objectives, which vary widely from project to project. Therefore, we do not recommend any specific duration of funding for a given program, except that it should be longer than the single year normally needed for organization and startup. The working group feels that a mix of long-term vs. short-term funding is appropriate for GEO. The working group strongly recommends that site visits be conducted by GEO for any long-term project (e.g., any GeoEd projects that are being considered for renewals, all Track 2 OEDG projects and all four-year GLOBE projects). The working group encourages the site visitors to evaluate projects on their individual merit as well as their contribution toward overall GEO objectives.

Modern scholarship in geoscience education encompasses both research (e.g., cognitive science, content development, evaluation) and delivery (e.g., course and curriculum design, technology, pedagogy). The working group recommends that GEO promote the integration of scholarly educational research in future projects. This goal should be addressed in conjunction with continuing efforts to integrate basic geoscience research into education venues.

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