Growing and Strengthening the Mars Science Community

A White Paper derived from a retreat held Nov. 6, 2003 at the California Institute of Technology

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A note regarding posting on the Mars Exploration Program Analysis Group (MEPAG) website (March 31, 2004)

This report was prepared at the request of the Manager of the Mars Program Office. Although this work was not formally chartered through MEPAG, this report is a community-based analysis product prepared in a MEPAG style. MEPAG is making it available on its web site in order to provide broad dissemination of material that is important to the Mars community and to stimulate discussion of its contents.

This report has been approved for public release by JPL Document Review Services (CL#04-1076), and may be freely circulated. Suggested citation:

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Executive Summary

The early 21st century promises to be a golden age for Mars exploration. A fleet of spacecraft is returning data at an exponentially increasing rate. Although these missions are sending back data that have and will revolutionize our scientific understanding of Mars, concerns have been raised about the size, composition, and overall health of the Mars scientific community. This report outlines some of the issues/concerns and possible solutions in this area, as voiced by a diverse cross-section of Mars scientists attending a one-day retreat at Caltech on November 6, 2003.

The concerns related to the potential growth and overall strength of the Mars science community, in priority order, were grouped in the following categories:

- Financial sufficiency for individual scientists
- Opportunity for involvement in Mars flight missions
- Quality of interdisciplinary research
- Access to mission data and the results of research
- The number and degree of self-sufficiency of early-career scientists
- Engagement of potential future scientists

Thirteen specific solutions to these issues/concerns were identified. Each of these solutions would have value, but there is a significant divergence of opinion within the participants of this retreat on the relative priorities. In general, however, the following solutions are considered to have the largest and most immediate impact. First of all, increased funding to the R&A programs will solve a great many problems. A low-cost solution that was strongly endorsed at this retreat is a resumption of the flight project student intern program. This was used very successfully on Viking, but has not been attempted since. Also of high priority are several issues relating to accessing and using Mars science information—this is currently a painful process which constitutes an unnecessary barrier to the entry of new scientists to the field. Finally, there are widespread strong feelings about improving the effectiveness of scientific public outreach, broadening the multi-disciplinary character of Mars science, and strengthening existing graduate education programs.

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1. INTRODUCTION:

A. Background

Since the advent of regular periodic missions to Mars starting in the 1990's (Mars Observer, Mars Pathfinder, Mars Global Surveyor, Mars Odyssey, Mars Exploration Rovers), perceptions of the planet have change dramatically. Conceptual and numerical models of ancient and recent Mars have been overturned by new measurements performed on these missions. Clearly, we are at an exciting juncture in understanding Mars and the potential that it was once habitable. The level of support of, and public interest in, NASA's Mars missions has also increased dramatically. Exploration of Mars is anticipated to continue at this level of through this decade, and initial plans are in place to continue this exploration program into the next decade. NASA's Mars exploration program is multi-disciplinary, as it must be to achieve the broad and critical scientific goals (understanding Life, Climate, Geology and the issues associated with Preparing for Humans).

Achieving these goals will require the expertise and support of a large, scientifically diverse community of researchers from a deep cross section of the Nation's finest institutions. A key strategic question, therefore, is whether the science population needed for future success will be in place when the future arrives. Concern has been raised that the present scientific population is aging, the training of potential replacements is unpredictable and possibly inadequate, and promising young scientists may not find career paths in the Mars program sufficiently attractive. The breadth and number of science disciplines involved in Mars exploration is also difficult to develop and maintain, and it has been especially difficult to achieve a desirable level of human diversity in the Mars program. As if to emphasize these challenges, our missions to Mars are becoming much more capable and the rate of data return is increasing exponentially -- the next planned mission, the Mars Reconnaissance Orbiter, will return an order of magnitude more data during its lifetime than all previous missions combined.

To consider these challenges, the Mars Exploration Program (MEP) convened a group of scientists and students of planetary science in a retreat at which the specific issues were identified and possible solutions were investigated. The retreat was held on November 6, 2003, at the California Institute of Technology. The purpose of the retreat was to evaluate these issues from the perspective of a representative set of scientists who are actively involved the Mars research. The output of the group, necessarily, represents the perspective of only one cross section of the science community.

Participants in the retreat were from a diverse group of scientists in various kinds of institutions involved in Mars research. Senior, mid-, and early-career scientists and graduate students were involved from a variety of scientific disciplines.

B. Contributors

Table 1. Contributors to the "Growing the Community" retreat, 11-06-03

Name	Affiliation	Employment
Arvidson, Ray	Washington University	University professor
Garvin, James	NASA/HQ	Program science

Gilmore, Martha	Wesleyan University	University professor
Head, Jim	Brown University	University professor
Kieffer, Hugh	USGS (Retired)	Research scientist
Leshin, Laurie	Arizona State University	University professor
McConnochie, Tim	Cornell University	Graduate student
Mischna, Michael	UCLA	Graduate student
Paige, David	UCLA	University professor
Rothschild, Lynn	NASA/ARC	Research scientist
Saunders, Steve	NASA/HQ	Program management
Schaller, Emily	Caltech	Graduate student
Stansbery, Eileen	NASA/JSC	Field Center management
Vasavada, Ashwin	UCLA	University professor

Conveners

Beaty, David	Mars Program Office	Program management
McCleese, Dan	Mars Program Office	Program science
Syvertson, Marguerite	Mars Program Office	Program support

C. The specific request of the participants:

The discussion prompt was specifically phrased as follows:

- What are the issues/concerns with the current and projected size and composition of the Mars science community? Some questions/assertions that have been posed include
  - Do we have enough capacity to analyze and interpret the growing number and volume of martian data sets?
  - Is the human diversity of the Mars science population sufficient?
- What are some possible solutions to address the issues identified?
  - How can we develop a pipeline of new scientists into the Mars program?

The retreat started with the following assumptions:

A. The future program for Mars exploration will proceed as currently planned.
B. Mars exploration will benefit from additional scientists
    a. Scientists of all levels of achievement
    b. Population of interest includes undergrads through senior researchers
C. Scientific disciplines need to be rebalanced among and within existing research topics:
    a. Disciplines (e.g Geology, Astrobiology, Meteorology, Aeronomy, others)
    b. Cross-cutting research topics (Instruments, Data Analysis and Interpretation, Numerical Modeling)
D. Code S is motivated to act in order to grow and strengthen the Mars science community. Funds for this purpose exist (within reason).

2. ISSUES AND CONCERNS IDENTIFIED

The retreat explored a wide range of issues, as is appropriate for a problem of this complexity. However, in order to produce logical and implementable solutions, the most important issues and concerns were grouped into the following six categories, which are listed in descending priority order.

A. Financial sufficiency for individual scientists

Many scientists, even those who are well-established, are concerned that NASA funding in Mars research is inadequate to sustain a career. This perception applies both to scientists who are trying to work full-time in the Mars program, as well as those whose intent is to be supported by NASA to work only part-time, e.g. faculty. A point that is difficult to over emphasize is that the perceptions of the established researchers impact recruiting and retaining new research talent. The younger participants in the retreat made two critical points: 1) The size of Mars grants is small enough that it requires winning several in order to remain solvent (and the risk of not having enough successful proposals will have consequences to the individual scientist); and 2) the challenges of achieving a satisfactory foundation of salary support are sufficiently severe that those with other attractive options frequently choose them. An adverse selection process applies here, since the people with attractive alternatives are those with the most talent.

Aspects of this concern include:

- There is an attitude of skepticism, or even cynicism, by some scientists regarding the long-range stability of NASA's funding of Mars research. The need for job security by individual scientists is a genuine issue. In the span of experience of this group, this has a gender-related effect, and it has caused many promising female scientists to either leave or avoid the field.
- Because of the way NASA is funded, it cannot make long-range commitments to Mars or any given target of exploration. However, individual scientists must make decades-long commitments if they are to be successful in their career.
- Retention of the present Mars community cannot be assumed.
- For scientists working part-time on Mars, the required level of engagement is much greater than the funding that is currently available.

B. Opportunity for involvement in Mars flight missions

There is insufficient opportunity to participate in NASA's flight missions, especially by young scientists. This is NASA's best opportunity to engage and inspire people, and we are not taking full advantage of its potential.

- Viking is an example of a project that has had long lasting benefit through its vigorous student intern program. This success story has not been repeated.
- Participating scientists are currently added too late to flight teams to allow for student and young scientist training opportunities
- The membership of flight teams is not sufficiently flexible. For example, it is not currently possible for teams to be finalized after selection.

C. Quality of interdisciplinary research

The Mars science community needs to increase its multi-disciplinary approach to Mars science.

- We need to increase our ability to pull in scientists who are not Mars specialists.
- Inter-disciplinary collaboration is insufficient at present to address the scientific problems involving intersections of geology, biology and climatology inherent in the study of Mars.

- A potential exception to this assessment is the Astrobiology Institute, which is well-positioned to undertake interdisciplinary research. However, the Institute's membership has been poorly integrated with the traditional Mars community.
- There is a perception that interdisciplinary research may offer an entrée to improving ethnic diversity by extending the reach of the Mars Program.

D. Access to mission data and the results of research

Management of scientific information is already a major issue in the Mars Program. Inadequate access to mission data constitutes a significant barrier to the addition of new scientists to the Mars science community. Issues in this area raised at the retreat include:

- Researchers not yet established in the field or not part of a flight team have great difficulty getting their hands on data from Mars missions. This problem increases geometrically when multiple data sets are needed.
- The lack of shared software tools for accessing and manipulating raw and processed data means that every individual must create his or her own tools. The cost, in time and money, of software development presents a significant barrier to new researchers.
- Data sets and products, such as cartography and ISIS efforts at the USGS in Flagstaff, are currently decoupled from the PDS – PDS is the advertised entry point for researchers needing Mars data. Frequently, incompatible data formats are encountered.
- The current pace of Mars science has no parallel since the Apollo program. There needs to be procedures for timely communication among scientists who either are involved in Mars science, or who would like to get involved, regarding results. Publication times are currently so long as to constitute a significant barrier.
- Successful MDAP and RA proposals promise derived products that will be made available to the community through the PDS. However, experience shows that few PIs are following through on their promises.

E. The number and degree of self-sufficiency of early-career scientists

Between the time of their departure from a university (after either a PhD or a post-doc) and the time of their first success in grant competition, a young scientist is most vulnerable. This period can last many years, and many innovative people are lost to science in this stage. By virtue of their experience, senior scientists are more capable than the junior scientists -- young scientists are at a severe disadvantage in direct head-to-head competition.

- In some scientific programs, young scientists are entering the competitive environment without either the breadth and depth of knowledge and experience that NASA currently requires of Mars researchers
- Students know little of it and young scientists do not understand NASA's proposal process.

F. Engagement of potential future scientists

Current outreach strategy communicates the Mars message to the average student. This strategy is valuable for its impact on the voting public, but it does not generate a pipeline of scientists feeding the Mars program. NASA also must work to engage students (at all levels) who have that special spark or interest in science. Aspects of this issue raised in discussion included:

- As undergrads make their choices among possible majors they are unaware that planetary science, much less Mars science, even exists. The students and young scientists participating in our retreat spoke of discovering planetary science "by accident".
- It is evident that Mars science does not have a meaningful presence at our colleges and universities. There are only about a dozen universities who are seriously involved in Mars research, and perhaps only about twice that number who are involved at all.
- One consequence of focusing outreach on the average student is that ethnic diversity among scientists suffers.

3. POSSIBLE SOLUTIONS:

In the retreat, our discussion of issues and concerns was very wide-ranging. In discussing possible solutions, for each problem area identified above, we attempted to identify a few solutions that may have a significant impact and which could be set in motion most easily. In many instances, this process led to focusing on the problems that have feasible, actionable solutions. Our goal, then, is to trigger some initial progress on these issues. At some point in the future, further work on the details will be needed, and follow-up monitoring and metrics are essential.

ISSUE A. Financial sufficiency for individual scientists
Solution Summary: Enhance the existing R&A programs, increase the size of the awards, increase the number of years of the awards.

> **Proposed Solution #1**. **Enhance existing R&A programs**. We believe that the growth and future strength of the Mars science community depend critically upon the perception within *academia* (the SOLE source of scientists) that NASA supports science and a diverse group of scientists. Application of stable funding to pursue basic research and data analysis, distinct from the activities of flight projects, is the most visible and dramatic evidence of that commitment.
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> Scientists pursuing lab experiments, field studies, theoretical work, and curiosity-driven (as distinct to mission-driven) research provide depth and context for our investigations of Mars. It is quite evident that this community of scientists is the very reservoir of people and source of discoveries that, in turn define, flight projects.
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> - The size of monetary **awards for research** should be increased, using as a guide NASA's astrophysics and Earth R&A programs. The Mars and Solar System Science Programs must tackle *grant* size if their programs are to become attractive.
> - The duration of the awards should be increased, if possible.
> - Increase confidence within academia in the 'bread-and-butter' research *grants* by increasing the funding allocated to R&A and Mars data analysis programs.
>
> But this should not be viewed as a separate endeavor.

ISSUE B. Increase opportunity for involvement in Mars flight missions
Solution Summary: Student intern program for Mars missions.

Proposed Solution #2. Following the model developed by Viking, NASA should create **an intern program for Mars missions** and make this intern program a formal part of future missions, including MRO. A surprising number of the leaders of the Mars exploration program today were Viking interns. Many of them feel that the Viking experience was the highlight of their career.

- Students and established, but inexperienced scientists can be made interns associated with science, development, and operations teams for periods long enough that they become productive contributors. Internships that are less than a full-time month are unlikely to be very valuable and will be a net drain on the host team.
- In such an intern program, we believe it would be valuable to establish selection criteria that expand the human diversity of the Mars science community.
- Interns must be welcomed and hosted by flight projects. Full incorporation of interns in to working teams is essential to the success of the Mars Intern Program.
- Selection of interns should be via Code S. All candidates should prepare a proposal. Students will gain very valuable experience writing proposals.

ISSUE C. Increase interdisciplinary research
Solution Summary: Convene technical workshops and symposia, interdisciplinary NRAs, extended visits by established Mars scientists.

While the majority of missions flown in the Mars Program over the past 10-years have focused on remote sensing, during the next two decades of the Mars program the importance of rovers and laboratories on the surface will be greatly amplified. We will be in the middle phase of the sequential exploration strategy described by MEPAG with the phrase, "seek, in-situ, sample". This phase of exploration requires advancements in in-situ geochemical and biochemical analysis techniques that rely on improved understanding of the martian surface. Additionally, the infrastructure and expertise for analysis of returned samples is not yet within the Mars program or in planetary science more generally. Non-planetary scientists offer to the Mars Program fresh and innovative perspectives and critical research skills. The advent of the Astrobiology program is a current example of the benefits of the marriage between Earth and planetary scientists.

- **Proposed Solution #3**. Convene technical workshops and symposia that bring Mars scientists together with terrestrial researchers on timely topics.
- A recent example of this is the Mars Polar Conference sponsored by LPI that attracted terrestrial polar researchers. Workshops that include field experience are critical for better understanding of surface processes. Mars scientists should also be encouraged to convene special sessions for planetary conferences and to contribute papers to conferences that typically do not include planetary research, e.g. the International Geoscience and Remote Sensing Symposium (IGARSS).

Proposed Solution #4. Encourage collaborations by adding interdisciplinary research NASA NRAs. Call for investigations involving researchers from multiple disciplines.

Possible Solution #5. Support extended visits by Mars scientists to academic departments and NASA Centers that emphasize sciences other than planetary. This could be accomplished using as a model the JOI/USAAC (Joint Oceanographic Institute Distinguished Lecturer Series) that sends scientists to undergraduate and graduate institutions to discuss results of the Ocean Drilling Program (http://www.joiscience.org/USSSP/DLS/DLS.html). Imbedding Mars scientists in non-planetary institutions will help to draw new scientists into our programs, as well as broaden the base of research for the visitors themselves.

ISSUE D. Improve the science community's access to mission data and the results of research
Solution Summary: Support expert **development of user-friendly software tools for handling, displaying and intercomparing data acquired by flight instruments. Improve the access to and timeliness of the publication of results from Mars research.**

Remove the barriers to accessing and utilizing Mars mission data sets that currently exist for those who are considering Mars as a research career. Provide the software tools and standardized data formats needed by non-specialists to handle data available today and those very large volumes of Mars data to come from future missions. Archival of instrument data in the PDS is insufficient, but investments in utilities for handling data can readily transform PDS into a source of information about Mars.

Possible Solution #6. In the near term, support through MDAP and CDP (Critical Data Products Initiative) reconciling pointing and timing discrepancies that currently make it difficult to geometrically register Mars datasets. Establish and require application of uniform standards for data labels, geometry and other ancillary information by flight investigators, PDS and USGS.

Possible Solution #7. In the longer term, support the development of user-friendly software tools that enable many more researchers to access, analyze and interpret Mars data. Support portable well documented code libraries, as well as user-friendly interactive applications and web-based interfaces with data. Examples include: 1) geographic information systems that allow users to easily map, overlay, and intercompare datasets; 2) accurate, up to date online browsers that make it easier to find data; 3) expert systems that enable non-experts to apply standardized, peer-reviewed data analysis techniques in real time; 4) online modeling tools that allow wider use of model results and modeling capabilities by the Mars community. Tools should be developed primarily by active researchers, e.g. users, in the community with specialized knowledge and skills, supported by software architects.

Possible Solution #8. Establish a mechanism to publish Mars research in online journals to speed and broaden the dissemination of research results. This approach has helped other disciplines make great strides in this area. For example, the biomedical community has successfully created two open access *peer-reviewed* journals (http://biomedcentral.com and http://plos.org) that are supported by author publication fees. NASA should sponsor a pilot program to establish a Mars-specific, peer-reviewed, open access online journal that offers rapid, peer-reviewed publication of in depth papers, and reach Mars scientists in a wide range of disciplines.

- Posting preliminary results prior to peer-review could also be valuable. The Physics and Astrophysics communities have made effective use of a free, e-print server archive (http://arxiv.org) permitting rapid posting of non-peer reviewed papers, many of which are later published in peer reviewed journals.
- In order for this solution to be valuable, we would need to ensure that we don't inadvertently end up encouraging the posting of half-baked and immature papers. It certainly isn't improving the quality of the next generation to make them think that they can just post their term papers as 'published' work. The peer-review process is an important part of verifying the quality of "publishable results".

ISSUE E. The number, diversity, and degree of self-sufficiency of early-career scientists
Solution Summary: Strengthen existing graduate programs, improve graduate selection criteria, and support cross-institution education, and training programs.

There are several issues with the pipeline delivering young scientists to new careers in competitively-based Mars science: The number of graduate programs which constitute the primary pipeline is limited—this impacts diversity, both intellectual and otherwise. In addition, the new scientists emerging from these programs have widely varying degrees of self sufficiency. Concerns may include not only the level of technical experience and ability (especially in highly specialized areas such as spectroscopy), but also competency in the processes necessary to function within NASA's funding system.

Appendix 1 lists the dozen major institutions that currently train the bulk of Mars scientists. NASA can meet its current challenge to strengthen and expand its Mars program by expanding its support for faculty and institutions that train Mars scientists. We would clearly improve the cultural and intellectual diversity of the Mars science community if additional institutions were able to join in the concentrated training of Mars scientists. A component of NASA's expanded support for training should a focus on the recruitment and training of females and underrepresented minorities in order to create a more diverse next generation population of Mars scientists.

Possible Solution #9. **Strengthen the existing graduate programs.** The graduate education environment is complex, and there are many different positive and negative influences on the faculty, the students, and the universities that affect their collective ability to deliver qualified additions to the Mars science community. Some suggestions for things that could be improved include:

- Develop proposal selection criteria for both missions and R&DA programs that specifically reward the involvement of young scientists, including graduate students, and especially females and minorities. It is important to teach the young scientists about the proposal process. However, under the current circumstances proposals in which professors and graduate students are the principals may be seen in peer review to likely be less productive than those from senior researchers and postdocs. Increased support for the NASA Graduate Student Research Program, and the initiation of a Mars-focused component of that program, would also be beneficial.

- In Mars research and analysis program proposal review criteria, introduce a category that is like the 'Cost-effectiveness category' that is along the lines of: "Importance in graduate education and mentoring of the next generation of scientists".
- Add a "Young Postdoc/Mentor Program" where a young researcher can apply to work at an institution with a mentor for 1-3 years. This is potentially very important--it would help the person to get independent funding but be mentored as well.
- Help fund the necessary support staff to maintain the graduate education pipeline. The Canadian National Science and Engineering Research Council has a grant category called Discovery Grants which includes funding for technical and support staff—this would be extraordinarily helpful.

Possible Solution #10. Form a **rigorous, cross-institutional education and training program** (tentatively dubbed "University of Mars") that would teach graduate-level students (and faculty) how to reduce, process and analyze the wide-range of spacecraft data soon to be returned from Mars. In order for this solution to be effective, it is critical that such a program be initiated as quickly as possible, potentially in summer 2004, in anticipation of the return of data from MRO and subsequent missions.

Possible Solution #11. As has been discussed in previous sections, student and young scientist involvement in spacecraft missions should be given a high priority by NASA. Such involvement should be encouraged in all stages of the process, from instrument development to mission science planning to returned data processing. A large fraction of scientific analysis of spacecraft data depends first on processing the data, a "menial" task often performed by graduate (and undergraduate) students. If students were involved in the early stages of the instrument development process -- in essence, teaching the students how the instrument works and preparing them to handle the type of data to be returned – the student's time would be far more productive, both for them and for the team to which they belong. Instrument PI's should be actively encouraged to include students and junior scientists on development teams not only for the sake of their own instrument, but also to train the "next generation" for the myriad considerations involved in the design and development of a spacecraft instrument.

In addition, there are existing "Presidential Young Investigator Awards" and other such grants which are available to the science community much broader than just Mars. We should root these out and get people to apply. Use program management to be sure that excellent new young planetary investigators are represented in the awards. Establish a "Post Doctoral researcher" component of the program or a "young assistant professor" component.

G. ISSUE F. Reach out to potential future scientists
Solution Summary: Improve EPO's reach to undergraduates.

Students with an aptitude for science and an early interest in Mars are often unaware of how to pursue this interest and are lost to other fields of research. For example, since planetary science and Mars research are conducted at only a very small number of academic institutions, only a tiny fraction of undergraduates have access to role models that might help them figure out how to pursue a Mars-related career path. Raising awareness about planetary science as a viable career must be a part of the Mars program's outreach strategy if the Mars science community is to be expanded and diversified.

> __Possible Solution #12__. **Create a specific element of Mars EPO that will reach future scientists** at all levels - from K-12 students through undergraduates. Informative websites should be developed that lay out stepping stones at all levels leading to careers in Mars science. These websites should especially advertise Mars related summer internship programs such as the NASA Academy, NASA USRP and other programs available to undergraduates. In order to foster the interests of younger students, the Mars EPO effort should recruit current Mars scientists to lecture to K-12 science classes about their work. In addition, Mars EPO should actively support local science fairs by offering awards to Mars related student projects, and Mars researchers should be encouraged to participate in judging and mentoring of young students. Collaborations with existing television shows and networks that focus on science for students should also be pursued; potential partners include PBS's Dragonfly and RealScience! series, Discovery Kids, and NASA's Kids Science News Network. Museums with Mars programming should be encouraged to bring on student interns to be trained as explainers and develop new programming for their peers, such as the Association of Science and Technology Centers' YouthALIVE! program which involved underserved youth.

> __Proposed Solution #13__. Develop a list of Mars experts who are willing to give **undergraduate directed lectures and lecture series** at institutions around the country. This would put planetary scientists in contact with scientifically motivated undergraduates. The speakers list should be *aggressively advertised* to science faculty nationwide. The lecturers would be strongly encouraged to discuss Mars related careers with their audiences, and should be provided with information on Mars and planetary science-related undergraduate research opportunities (e.g., PGGURP, Space Grant), as well as information on relevant graduate programs. Since most academic institutions have a limited amount of funding available for hosting guest lectures, support for lecturer travel and honoraria expenses would enhance the impact of this program by increasing the number and diversity of participating institutions.

__4. DISCUSSION:__

__Comments on Ethnic and Gender Diversity in the Mars Program__

As is unfortunately the case with the science and engineering enterprise in almost all disciplines, the current Mars science community is unbalanced in gender, race, and cultural background relative to the make up of the citizens who fund the program. This is a symptom that has many causes. There is a linkage to many of the issues and concerns described above, but there are additional root causes that are endemic to American society. Lack of diversity means that the full potential of the workforce that could be brought to bear on these problems is not being realized.

We note that the participants in the retreat are experts in science (or are students of science), not experts in minority affairs, employment policy and law, affirmative action, or sociology. Thus we are neither in a position to offer a systematic, professional analysis in this area, nor are we in a position to envision the full range of possible solutions for improving the human diversity of the science population. However, based on our personal experiences we offer the following simple suggestions.

> Students could be introduced to scientist role models at an early age in elementary school through literacy programs such as ReadingFirst (a mandated Title 1 program) and Read Across America. These programs provide opportunities to engage students and to emphasize career options. A compilation of biographies could describe how specific scientists were drawn to the field and their school and career history; included could be associated activities/lessons that pertain to the scientists' fields of research. Later, middle school students could work with enhanced curricula in integrated science courses to encourage them to pursue more challenging and engaging science courses (moving them from a non-college to college track). In high school, students could intern with local colleges and universities, including Minority Serving Institutions (MSIs) that have partnered with leading Mars institutions (universities and NASA centers) in Mars research and mission proposals. University students at MSIs could intern with these lead institutions as a component of a partnered research or mission proposal. As part of these joint proposals, Mars scientists could spend time at MSIs over a few weeks to assist in the development of new laboratories or data analysis facilities.
>
> Finally, broadening of the potential recruiting field and the interdisciplinary science approach to include agricultural schools, where MSIs often excel, would bring in experience in plant and soil sciences, life sciences, and molecular biology and attract a more diverse group of scientists than currently involved in traditionally Mars-focused research areas of physics, geology, and planetary science.

Metrics are needed
It is important that the current state (e.g. size, diversity) of the Mars science community be examined quantitatively and that future changes be tracked with carefully chosen metrics. In order to do this, it will be necessary to establish a specific definition of "the Mars science community", and to maintain this definition for several years. Obvious key issues are the distribution of age, gender, geography, race, and cultural diversity, as well as of course, scientific discipline.

Some of the issues associated with defining the Mars science community in a specific enough way that it can be tracked include:

- The Mars science community can be split into two broad groups: Those who are working full-time on Mars science (i.e. those with no other source of funding), and those who have broader technical interests and a broader base of financial support (terrestrial, cosmochemistry, other planetary). Very substantial contributors to the Mars exploration program reside in both subsets. Do we count one or the other, or both?
- Do we count support personnel (e.g. technicians) and graduate students, or only PIs?
- Do we count only Mars-related scientists who are receiving money from NASA? Are there scientists making use of Mars data in research programs funded by other entities, and should they be counted?

– Is the key metric dollars or numbers of scientists?
– Do we have a systematic and appropriate means of collecting the data and keeping it up to date?

A small group of scientists should be charged with developing the required definition.

The cross-cutting nature of the possible solutions.
We have identified six areas of issues and concerns in the general topic of Growing and Strengthening the Mars science community, and over double that number of implementable solutions. During the retreat, it became apparent that several of the solutions apply to more than one of the issues and concerns. These relationships are illustrated in Table 2.

Table 2. The cross-cutting nature of many of the solutions.

Solution #	DESCRIPTION	A. Enhance and stabilize funding for science research	B. Increase opportunity for involvement in Mars flight missions	C. Increase interdisciplinary research opportunities	D. Increase availability of data and results	E. Increase opportunities for training and funding for early-career scientists	F. Increase the number, diversity, and interest level of potential future scientists
1	Enhance existing R&A programs	HIGH		MED		MED	
2	Create intern program for flight missions		HIGH			HIGH	HIGH
3	Convene technical workshops and symposia that bring Mars scientists together with terrestrial researchers			HIGH			
4	Expand NASA NRAs that call for interdisciplinary research involving co-investigators in multiple disciplines			HIGH			
5	Support extended visits by Mars scientists to academic departments			HIGH			
6	Reconcile pointing and timing discrepancies that currently make it difficult to geometrically register Mars datasets				HIGH		
7	Support the development of user-friendly software tools that allow many more researchers to access and analyze Mars data.		HIGH		HIGH	HIGH	
8	Publish online journals that offer rapid peer review and open full text access			HIGH	HIGH	MED	
9	Develop proposal selection criteria for both mission and R&DA programs related to the involvement of young scientists	HIGH	HIGH			HIGH	
10	Create rigorous, cross-institutional education and training program ("University of Mars")					HIGH	
11	Young scientist involvement					HIGH	MED
12	Create specific element of Mars EPO that will reach future scientists						HIGH
13	Support undergraduate directed lectures or lecture series					HIGH	HIGH

Solution priorities.

All of the possible solutions described above would have, if implemented, a beneficial impact on NASA Mars exploration program and on the science community that it supports. However, we recognize that it may not be possible to implement them all. In assessing the relative priority of the possible solutions, it was necessary to recognize that there is a rather wide range of opinion at the retreat. Despite this variation, several conclusions were drawn.

- Enhancing the existing R&A programs is thought to have a significantly greater value than the other solutions, but it is recognized that it also has a significantly greater cost. Nevertheless, this solution is very strongly endorsed as addressing the most aspects of the challenge quickly and effectively.
- A HIGH priority is given to the intern program for flight missions. It is a solution that is relatively easy to implement, has extremely high-value, and a relatively low cost. The two information management solutions are rated as HIGH priority. At first glance information management may not appear to have an immediate connection to growing the community, but our view is that this constitutes a critical barrier to the entry of new people. Many of the other solutions will not come to fruition if the barriers to information dissemination are not solved. Also rated in the category of HIGH priority are improving the effectiveness of scientific public outreach, broadening the multi-disciplinary character of Mars science, and strengthening existing graduate education programs.

  The improvement of the human diversity of the Mars science community, e.g. ethnicity is highly desirable. And, although accomplishing this by means of establishing specific proposal selection criteria is rated LOW in Table 3, this is a reflection of our strong sense that changes in this area happen will occur only in the context of the other solutions; not - as a stand-alone action.

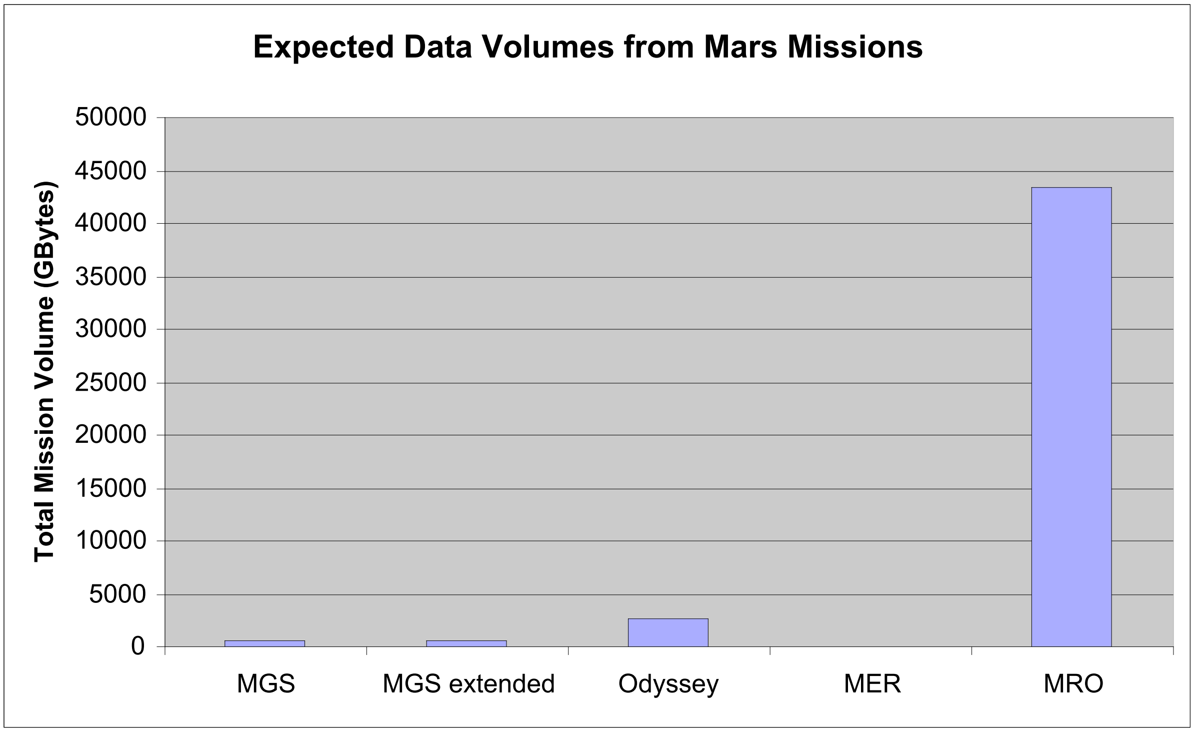
Table 3. Relative priority of the solutions discussed in this report.			
Solution #	**Concern #**	**DESCRIPTION**	**RELATIVE PRIORITY**
This solution has a much higher value and cost, and is separated from the other solutions			
1	**A**	Enhance the existing R&A programs	**V. HIGH**
Listed in decreasing order of approximate overall priority			
2	**B**	an intern program for flight missions	**HIGH**
7	**D**	support the development of user-friendly software tools that will allow many more researchers to access and analyze Mars data.	**HIGH**
6	**D**	reconcile pointing and timing discrepancies that currently make it difficult to geometrically register Mars datasets	**M/H**
12	**F**	create a specific element of Mars EPO that will reach future scientists	**M/H**
4	**C**	NASA NRAs that calls for interdisciplinary research involving co investigators in multiple disciplines	**M/H**
9	**E**	Strengthen graduate education programs by adding selection criteria which support student involvement.	**M/H**
11	**E**	End-to-end student involvement	**MED**
10	**E**	A rigorous, cross-institutional education and training program (tentatively dubbed "University of Mars")	**MED**
3	**C**	convene technical workshops and symposia that bring Mars scientists together with terrestrial researchers	**MED**
8	**D**	publication in online journals and that offer rapid peer review and open full text access	**MED**
13	**F**	undergraduate directed lectures or lecture series	**LOW**
5	**C**	Extended visits by Mars scientists to academic departments	**LOW**
Note: All of these solutions will be beneficial. The criterion used to establish the relative priority in the right-hand column was the magnitude and immediacy of the impact. However, some of the solutions in the lower part of this list will have good long-term benefit, and should be considered for implementation.			

APPENDIX 1. LIST OF MAJOR MARS UNIVERSITIES IN 2003.

The following institutions of higher education (listed alphabetically) receive the lion's share of the Mars funding, and produce a disproportionate share of new Mars-oriented Ph.D. scientists. In part, this reflects the strategic choices made by these institutions regarding their commitment to the Mars exploration program and involves faculty hiring decisions and infrastructure investments. There are perhaps twice as many other universities receiving far less support from NASA for Mars programs that produce many fewer PhD students. The list below constitutes the primary pipeline from which new talent enters the Mars science community in the United States.

Arizona State University
Brown University
Caltech
Cornell
Harvard University
MIT
UCLA
University of Arizona
University of Colorado
University of Hawaii
University of Washington
Washington University, St. Louis

APPENDIX 2. EXPECTED DATA VOLUMES FROM PAST AND PLANNED MARS MISSIONS.



Note: This histogram primarily illustrates the jump in orbiter data volume, which tends to be bit intensive. Although the scale is different, a similar jump is seen when Pathfinder data volume is compared with MER. The amount of human interaction with landed data is much higher per bit than for orbital data.