Compiled Perspectives on STEM Education[1]

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with contributions from

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Introduction

These Compiled Perspectives are the result of a wide-ranging online discussion on the subject of science, technology, engineering, and mathematics (STEM) education, which I had the pleasure of initiating. Participants ranged among students, teachers, and professors, each with markedly different perspectives on the subject. In general, I aimed to invite individuals from every STEM-related program which had significantly informed my own views, including the Montgomery Blair HS (MBHS) Magnet, the Hampshire College Summer Studies in Mathematics (HCSSiM), the Intel Science Talent Search 2008 finals, and the University of Chicago, and even beyond these groups, several more contributors heard of our project and pitched in. Some of us were offered extraordinary educational opportunities as youngsters, some of us nearly -- or actually -- became "lost potential," and some of us made a career out of educating unusually talented students. Our broad discussion has produced a wealth of ideas, which we wish to share with the National Science Board and the Committee on Education and Human Resources.

-- Louis Wasserman

Improved Retention and Training of Potential scientists.

Many high-STEM-ability high-school students fail to realize their full STEM potential, or leave STEM entirely at the college level. It is simpler to attempt to retain such students in STEM and to enhance their high-school STEM experiences than to recruit

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1. Version 2.. Some limited changes have been made following the NSF panel.
2. Louis can be reliably contacted at wasserman.louis@gmail.com. For more about Louis visit http://www.google.com/profiles/wasserman.louis
3. Learning Unlimited was spawned out of several ESPs (Educational Studies Programs) across the country. ESPs will be discussed later in this document. For more details on LU, see http://learningu.org/

additional talent. **These students could be described as the low-hanging fruit in the NSB's efforts to, in the words of the Charge[4], "produce the next generation of innovators."** These students represent a "pool of potential talent in our society that currently is overlooked, under-developed, and underutilized," and these students should be a key target of our nation's strategy for developing STEM talent.

Gifted students are typically well aware that they aren't being sufficiently challenged, and considerably more aware of that fact than the school system responsible for evaluating them. Such students will almost certainly do well by their school system's standards -- and frequently by the measure of any standardized test -- but the degree of challenge implied by that standard typically demands almost no effort from them. The school system will consider such a student a success story, and a valuable data point, but certainly not a student with woefully unmet needs. MBHS Magnet teacher James Schafer comments,

> *"It seems to me that there exists a sort of laissez-faire attitude toward the bulk of the accelerated students because there is a belief (right or wrong) that those students will succeed regardless of who teaches them. This of course is both true and false. For many good reasons, there is always a push to get lower achieving students up to the level of the mainstream population, and millions of dollars are spent to do this. But the question is: Why is the other end of the spectrum neglected? Why is it acceptable to essentially hold kids back?...Success for the gifted student can only be measured against their potential, and if gifted students are not provided the opportunities to reach their full potential, then we have failed those students as an educational system. True, no child should be left behind, but no student should likewise be held back."*

Many of our most talented students live in an environment where teachers don't have time to to support students ready for more challenge than standard classes can offer. Given the intense social stresses upon such a student, both from her teachers' inability to accommodate her interests and from the pressure on every student to fit in, it is far too easy for a student to convince herself that her best strategy is to attempt to lay low, minimize the extent to which her potential shows up in class to make her look different from her peers, and simply accept that she cannot find an outlet for her potential. This is, to say the least, a strongly demoralizing environment.

It is also painfully easy for a potential scientist simply not to realize that her interests coincide well with a career in math or science. Amy Estersohn, a UChicago senior majoring in English, adds,

> *"What I didn't realize [during high school] was that my hanging out in the library during free periods, blasting my Pink Floyd on my discman, and jiggering around with a proof for the LaGrange Error Bound Theorem and explanations for patterns in polar coordinates, or that my high school boyfriend and I would discuss special relativity over Chinese food, were good indicators that I would enjoy a STEM major...The difference, for me, was that these experiences were self-initiated, exploratory, and with intrinsic rewards. These were jam sessions, not auditions."*

Quite simply, talented students can become lost potential without adequate exposure to a sense of what STEM advanced studies and careers are like. To a grown scientist, it is obvious that Amy would potentially very much enjoy a STEM major, but it might not even occur to a student that their informal interest might become something more than a hobby. To produce STEM innovators, students will first need to realize what the life of such an individual is like; the information popular culture currently provides is minimal and misleading at best. We don't adequately communicate to our students that scientists are exciting, creative, social people with a driving curiosity about the world.

Amy's "symptoms" are all characteristics of a potential scientist, but few high school science classes would make that point clear -- that "self-initiated, exploratory, and intrinsically rewarding" experiences are part of a scientist's everyday life. It is depressingly easy for a student like Amy not to realize that students just like her grow up to become groundbreaking researchers. We must better inform the next generation about what qualities are characteristic of a STEM innovator, including creativity, a driving curiosity, collaborative skills, and determination.

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4. http://www.nsf.gov/nsb/meetings/2009/0824/charge.pdf

These are two key ways that the nation loses potential for innovation -- insufficient challenge and lack of community leading to a potential innovator becoming disillusioned, and our failure to communicate the characteristics expected of a STEM innovator, and encourage students with a recreational interest in STEM to pursue their interests in the long term. Given the logistical constraints -- that not every student will be interested in a STEM career, that different students will learn at different rates -- the need for effective programs aimed at educating future STEM innovators should be clear.

Supporting STEM Training of Future Innovators.

In this section are described some aspects of successful STEM programs that seem particularly important to us.

Young scientists report that aside from access to challenging and/or new material in their field(s) of interest, the formation of community is the most important property of programs that positively impacted their development. (The most frequent comment made by HCSSiM participants, for instance, is along the lines of "I have finally found other people like me.") Every student needs a supportive environment, and for a potential scientist, a group of like-minded students provides both a comfortable social group and opportunities for discussion and collaboration. Richard Rusczyk, who founded the Art of Problem Solving website, has this to say in his article "The Calculus Trap"[5]:

> *"If ever you are by far the best, or the most interested, student in a classroom, then you should find another classroom. Students of like interest and ability feed off of each other. They learn from each other; they challenge and inspire each other...[a student exposed to other similarly talented minds] is going to grow by great leaps, led and encouraged by other students...In addition to this intellectual enrichment, the social enrichment of being amongst like-minded peers is invaluable. My closest friends now are doctors, bond traders, consultants, lawyers, professors, artists, and so on. The common thread among them all is that they all enjoy using their minds. I met nearly all of them through activities or employment that selected for thinkers."*

Any class realistically requires 12-25 students. Given any advanced STEM topic, creating a class around that topic requires finding this many students interested in pursuing that topic further -- which requires a program of sufficient size. Magnet schools and magnet programs within schools generally meet this criterion. (Magnet programs will be discussed extensively in the next section.) For example, the MBHS Magnet program has 100 students per year, which has for many years been enough to enable the offering of specialized classes ranging from Complex Analysis to 3D Graphics to Marine Biology. Intensive summer programs devoted to STEM also draw enough students to offer advanced study. Pooling students across a school district or county (that otherwise has no magnet program) can help to assemble classes ready to study subjects beyond or distinct from the standard curriculum.

Collaborative learning is not only an effective educational technique on its own, and a key skill of STEM researchers and innovators, but can help to foster the community essential to retain STEM students. The collaborative approach plays a key role in the MBHS Magnet and HCSSiM, in particular, with outstanding payoffs. Collaboration is one of the best ways to establish tight bonds of community within a group of like-minded students. In short, collaboration should absolutely be a key aspect of any STEM education program.

Competitions are effective at bringing students together from diverse geographic areas; for example, several contributors to this document were brought together at the Intel STS finals. However, we have little faith in the effectiveness of competitions as motivators. Besides the fact that competitiveness differentially attracts students in ways correlated to gender and ethnicity, its attraction to students is not necessarily correlated to the attraction of the actual field of study. We have seen a large number of students participating in mathematics and research competitions only to drop the subject as soon as possible after entering college. We advocate that competitions be de-emphasized in

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5. To read this excellent article, visit http://www.artofproblemsolving.com/Resources/AoPS_R_A_Calculus.php

favor of collaborations, and note that there are competitions that combine collaboration with competition effectively, in particular the MCM[6] and especially the FIRST Robotics Competition[7].

We believe that **students need enriched experiences much more than they need accelerated experiences**. An enriched class will go deeper into the how and why of the subject material, and generally amplify students' understanding of the topic, while acceleration is simply the practice of placing students in classes more advanced than is typically appropriate for their age. Innovation is not possible without extraordinary depth of understanding, something the Intel finalists among us are keenly aware of. If we expect to produce future STEM innovators, they must receive a solid and enriched science and math background, for only with a higher level of understanding can they succeed. **A thirteen year old taking an AP Calculus course will learn no more than a sixteen year old taking the same course -- the thirteen year old will simply have learned it earlier. We do not consider this an improvement.**

As it stands, students across the nation run out of STEM courses to take by their senior years in high school (and sometimes earlier). These students are gaining no more experience than their less accelerated counterparts; they are simply gaining it faster. To encourage STEM innovation, this is not sufficient. These students require a deeper understanding of their field than standard curricula can offer, and accelerating them has no purpose save as a low-investment tactic to keep talented students busy. Acceleration is frequently lauded as challenging students to work harder and better, something that students respond to well, but this is an attribute of harder classes, not of more advanced classes, and the two are not the same thing. Enrichment, while frequently little more than a buzzword, means something to us: it means studying topics in all their depth, enjoying the greater understanding that comes from learning the underlying mechanism behind things, and it does not at all mean a "softer" or "easier" class. **We believe that a deep, demanding course is every bit as stimulating to the talented youngster as a simply more advanced course.**

Finally, the pressures of the college application and admission process have contributed to over-acceleration in mathematics in particular. In our experience, students regularly arrive at college having taken some form of calculus course but without sufficient algebraic skills to succeed in college calculus courses. In the Montgomery County school system (which includes MBHS), the school system has accelerated many fifth-grade students into sixth-grade algebra. We concur that some of these students may be ready for such a course, but many students being put in algebra courses lack a solid foundation in fifth-grade mathematics. Magnet teacher David Stein commented in an 8/6/09 story on radio station WTOP, "We've copped out. Instead of learning fifth grade math at a rigorous level we're just putting kids into sixth grade math in fifth grade." One of the major challenges in providing enrichment systemically is meshing it with the present structure of secondary education. School-based courses will require both development and teacher training. Work outside of school can utilize existing experience, such as offered by various websites, such as MIT's OpenCourseWare,[8] or by local academic, industry, or community individuals, but cannot provide students with credit for or official evaluation of their work.

Research in high school is not right for every student, or even for every potential scientist. It is important that high-school students understand the research process, but the current trend is to encourage all gifted students (or even all students!) to work toward producing original research while in high school. However, these students are being pushed into original research with grossly inadequate experience; in particular, few of these students have any experience reading and understanding a modern STEM research paper. **We must significantly improve the quality of basic**

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6. Mathematical Competition in Modeling. See http://www.comap.com/undergraduate/contests/mcm/
7. FIRST: For Inspiration and Recognition of Science and Technology. See http://www.usfirst.org/
8. MIT makes its course materials publicly and freely available online. See http://ocw.mit.edu

STEM classes before we should consider pushing high school students into research.

Besides improving these students' STEM classes, they should be trained in the processes of research and given the opportunities to experience what research is like -- by assisting in research projects (particularly in laboratories), by attempting to read current scientific literature, and by investigating material that is new to them.[9] Finally, to avoid student and teacher misperceptions of these activities, students studying the process of research should not be labeled as "doing research," and that phrase should be reserved for the few students who actually set out to accomplish original research.

Magnet programs in STEM education.

Effectively teaching the most talented students is, in many respects, a significantly different ballgame from managing a typical classroom. In particular, the teacher must understand the material deeply enough to be able to provide for any reaction from the students. Teaching a course to the gifted requires a good deal of commitment from the teacher as well, as she or he must carefully track which students are following the material, which are not, and which students need more challenging problems to play with or ideas to think about.

Several of us have been given particularly outstanding STEM education at magnet programs across the country. Students, alumni, and teachers at the Montgomery Blair HS Magnet program in Silver Spring, MD, this editor included, formed a large proportion of the contributors to this document, and we will use this program as an example in this section. We are aware that not all school systems can realistically support magnet programs, but population centers may be able to support implementations of the magnet concept. (The next section will discuss ways to support STEM education in areas of low population density.) We outline key features of the MBHS Magnet program that make it successful, in the hopes that they could be replicated more widely. **We urge the NSF to find ways to support magnet-style programs across the nation.**

One key feature of magnet programs is the availability of classes which delve significantly deeper than standard high school materials. In the MBHS Magnet, these classes are typically developed essentially independently and from scratch by their teachers, who of course must also find answers to the out-of-the-box questions their students inevitably and frequently ask. Curricula borrowed from university courses are useful in this regard, but taking these curricula verbatim provides no additional enrichment beyond what these students would normally experience. To provide a seriously useful experience for their students, these teachers must devote considerable time to studying their subject and developing courses.[10] In addition, most regular teachers typically teach several sections of the same class so that they need to prepare fewer distinct lessons per day. The diversity of advanced classes available at magnet programs demands that individual teachers prepare more distinct lessons per day than a regular teacher.

Nevertheless, teachers at magnet programs frequently have no more planning time than regular teachers in their district. The demands of teaching one of these courses could be reasonably compared to taking a college-level course in the subject concurrently with the teacher's preexisting course load. No teacher can effectively teach a class of this type without consuming considerably more preparation time per class than a teacher for a regular or AP class. These teachers realistically need to understand the topic at a level comparable with the top students in the class, even given that those students will undoubtedly be exploring the topic outside of class. Typical teachers have nothing like the background needed to teach one of these classes; at a bare minimum, teachers for these classes should have majored in the subject and have done well in

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9. In the Appendix, proposals 1 and 5 directly address effective ways of providing this experience.
10. Some suggestions for reducing these demands, and improving these courses in general, can be found in proposal 2 in the Appendix.

their major classes.

A central component of magnet programs is extracurricular activities, which demand considerable time investment from teachers, who usually are not compensated for their time. At the MBHS Magnet, students can find a wide variety of popular academic extracurriculars, including the FIRST Robotics team, Envirothon, Computer Team, and Math Team. The common thread, of course, is that these activities enable students to find communities and explore subjects outside of the classroom, without the limiting factor of course prerequisites. These programs frequently consume several hours per week of teachers' time -- the FIRST Robotics team in particular demands from its sponsor around 15-20 hours a week for the six weeks of build season, leading up to two competitions lasting three full days each. Louis Wasserman adds,

> *"When I taught the Computer Team for a year and a half, I borrowed material from OpenCourseWare lecture notes for MIT graduate computer science courses, and my class of mostly high school sophomores devoured the material. No high school class could have offered them that. Only by bringing together this concentration of talent -- first by forming the Magnet, then by supporting the Computer Team -- could you find a way to satisfy these students' thirst for knowledge, by putting them in a room with a student who'd already been in their shoes and letting them do whatever topics they wanted."*

For students deeply interested in a subject, extracurricular exploration can be an outstanding source of stimulation, in particular exposing younger students to older students who share their interests. In addition, the hands-on experience provided by some of these activities is a valuable asset. We emphasize the key role of extracurriculars in supporting magnet programs, and note that unfortunately, most of the sponsoring teachers currently receive no support for their valuable advising work. (This is a nationwide problem in public secondary education -- teachers are neither compensated nor rewarded for sponsoring academic extracurricular activities, and so there is a paucity of teachers willing to add to their workload in these ways.)

The demands of teaching in a magnet program are unusually great -- in particular, the demands on such a teacher's time from preparing for unusually advanced or fast-paced classes go well beyond the demands upon regular teachers -- and the extra support provided for those teachers varies widely. The support provided to these teachers directly affects their ability to provide an effective magnet program. We suggest that the NSB outline guidelines for appropriate teaching load for teachers in programs such as these and guidelines for additional compensation for teachers sponsoring STEM extracurriculars, and that the NSF likewise provide some funding to ensure that teachers have the support they need to provide the most enriching and challenging education possible for the unusually talented students they serve. Those students are our best hope for the STEM innovators of the future, and they need the stimulation from the school system that only well-supported teachers can provide.

Supporting STEM outside population centers.

Qiaochu Yuan, who grew up in the Vancouver, WA public education system but eventually became an Intel finalist and now attends MIT, recounts:[11]

> *"I can't imagine how many otherwise brilliant scientists or mathematicians we lose because they never find a community that understands or values them. PROMYS and RSI were both integral to my development as a mathematician, and I value the community as much or more than the research experience. Science/math isn't done in a vacuum...the sooner young scientists are exposed to collaboration and the scientific community, the better... None of this would've been possible had it not been for a single teacher of mine. Having taught on the east coast, she was aware of all of these programs and competitions...Most people have no idea these programs or competitions exist."*

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11. Qiaochu mentions PROMYS, which is the Program in Mathematics for Young Scientists (http://www.promys.org/), held at Boston University, and RSI, the Research Science Institute, held on the MIT campus.

For students without a school program advanced enough to satisfy their needs, we emphasize that summer and other extracurricular programs can frequently provide the support a school system cannot. In particular, areas with low population density may simply never be able to support magnet programs or other sizable STEM programs, but programs outside the classroom can provide a similar support framework. Summer programs have the flexibility to implement many of the key features of magnet-type programs mentioned above, to find talented teachers and a large enough student base to support a sizable community of students who share an interest, and are generally a reliable means of providing this support for students like Qiaochu.

However, summer programs of this sort are currently not particularly feasible opportunities for underprivileged students. Dr. sarah-marie belcastro, who recently codirected the Hampshire College Summer Studies in Mathematics (HCSSiM), points out:

> *"Recently there was an article in the Chronicle of Higher Education about Ivies that host free summer programs for local youth who are unlikely to apply to competitive schools. They cite the cost per student per summer as being about $5K. That's about right for programs such as HCSSiM and MathCamp as well, and it's a ridiculous amount to ask a family of four with an annual income of $60,000 or less to pay for a summer opportunity -- never mind the travel expenses, miscellaneous spending money, or potential lost income compared to the student getting a job."*

We strongly urge the NSF to lend its support to intensive summer programs, which on their own simply cannot provide effective education while remaining affordable to underprivileged students.

In addition, we commend the model of the Educational Studies Program (ESP)[12], which offers programs such as Splash![13] and Cascade![14]. ESP programs are currently found at MIT, UChicago, NYU, and Stanford. In particular, the fledgling program at UChicago serves a population of students who have modest resources. Amy Estersohn, who works closely with UChicago ESP, says,

> *"...There's so much to love about ESP and ESP-esque programs: the enrichment really is enrichment, as you have people who love the thing they are teaching teach it to others...."*

Daniel Zaharopol, who served as MIT ESP Chairman for two years, adds,

> *"If you're from a middle-class background where summer camps are the norm, fine; but if you're not, it is intimidating to leave home for an extended period, especially for an academic program. An ESP can be a weekend, or once-a-week; it's a lot easier to get into that...They expose students to a huge variety of learning. You might not be sure that math is your thing...but if you go to Splash you can try a class out for an hour or two, and then go on to a class on quantum mechanics or evolutionary biology or Mayan culture. Essentially, they're a good place to discover what you love."*

ESP programs admittedly have a number of limitations. Splash! classes are too short to seriously develop students' understanding of a topic. (It is important for students and teachers not to equate having taken one of these brief classes with understanding the material. It is important for all concerned to understand that such a survey-type course does not equate to knowing or understanding a subject.) This problem is moderately alleviated with multi-week programs such as Cascade!, but no ESP program currently provides much in the way of follow-up resources to students.

Though ESP-type programs have limitations, the benefits -- namely, a sense of community and enrichment among the students and exposure to the collegiate atmosphere -- are non-negligible. In particular, we support the use of undergraduate and graduate students to enrich the education of high schoolers. In addition to being generally approachable, college students are often more excited about their work than

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12. http://esp.mit.edu/
13. Splash! is a one-day event during which college students teach 1-2 hour classes to high school students on a wide variety of topics. For additional details, see e.g. http://uchicago-splash.mit.edu/
14. Cascade! offers high school students five-week classes (taught by college students) in a wide variety of topics. Cascade! offers students the chance to go into greater depth than Splash! classes can offer.

professional teachers, and that sort of energy coming from a teacher is something unfamiliar to all too many public-school students. We might add that the experience of teaching younger students might draw more young, energetic college students into teaching as a career, and that has its own separate benefits. Finally, ESP programs are unusually scalable: MIT Splash! runs on a budget of less than $20 per student, and UChicago Splash! runs on far less. ESP programs have significant and nonnegligible limitations, but within those limitations they can be surprisingly effective.

Conclusions.

On the subject of STEM education, there do exist programs that work -- namely magnet programs and summer programs -- and that are largely responsible for developing much of the talent emerging from our public school system. These programs, however, are not necessarily available to underprivileged students, and some are being cut from perenially squeezed budgets. In particular, the MBHS Magnet, despite functioning in one of the wealthiest school systems in the country, has recently endured cuts that severely hinder its ability to provide the unique educational experience that has won it more Intel STS finalists in the past decade than any other school in the country, despite the Magnet's small size as compared to Stuyvesant HS in New York or Thomas Jefferson HS of Science and Technology in Virginia. That such an effective program would see its budget slashed so deeply is revealing of our educational system's current priorities.

Though the Obama administration's emphasis on teacher accountability with respect to test scores is commendable, that push will not provide any support for students who easily pass standardized tests but lack the encouragement to reach their much greater potential. As an example, Montgomery County Public Schools recently slashed MBHS Magnet teachers' additional planning time and cut several teachers, resulting in the loss of several several key activities and classes. These cuts to the MBHS program, in one of the nation's wealthiest counties, do not reassure us. The Montgomery County, MD school system has demonstrated all too clearly that programs for the most talented students are not considered a priority in this environment. **The NSF should help to fund program types that have demonstrated their effectiveness in this regard, particularly magnet programs and summer programs. The NSF's funding targets in this regard must include both operational costs of existing programs and startup funds for creating new programs using the existing successful models.**

It is a grim but unavoidable truth that students with high potential routinely fall through the cracks of most educational systems throughout our country. Many are aware that they don't have access to opportunities that some others have, but even more only know that they aren't as challenged as they could be. In terms of identifying and nurturing talent to become our next generation of innovators, these students can be considered the low-hanging fruit. We suggest that in many cases, it may be as simple as asking students if they feel challenged by their school's highest-level classes, for these students are frequently well aware that they have much more potential than their classes demand -- even beyond classes in the Advanced Placement or International Baccalaureate programs.

This leaves the question of how best to support these students. **We strongly urge the NSF to make a funded call for proposals for new kinds of programs aimed at gifted high-school students.** Our discussion spawned several ideas, each of which have their flaws, but which demonstrate the possibility of developing new methods for attacking this problem. Several examples of those ideas are reproduced below in the appendix.

There are clear and obvious limitations as to what the NSF can do to support STEM education. In particular, overhaul of teaching certification and hiring procedures and of classroom practices seem to be difficult or politically intractable tasks. Nevertheless, we have discussed several successful educational program models that it is well within the NSF's capabilities to support, and means of identifying and supporting potential scientists in the public education system. Most importantly, we strongly believe that there is room for much more additional creativity and ideas, and strongly urge the NSF to support the development of these ideas with a call for proposals backed by significant funding.

Appendix: Sample STEM Program Ideas.

1. *Research preparation classes.* To accomplish the objective of properly educating students about what it's like to do research, schools might offer a single-semester elective course entitled Introduction to Modern Research. This course would require students to select one of a list of modern research papers and to study it closely. (This course *should not* be restricted to the lab sciences, of course. Mathematics and computer science are fair game.) Students would be asked to explain the question addressed by the paper and, critically, why this question could only be answered with the methods discussed by the paper (e.g. why wouldn't another method work here?), and how these methods could be more readably framed. Though students would not be doing original research, they would gain experience in asking the questions a researcher asks: what methods can I use to answer this question? Is this comprehensible to the reader? How can I present this information more readably? The question remains, of course, how to train teachers to be able to guide students through this process.
2. *Course development for magnet programs.* The NSF might fund programs to develop curriculum modules for specialized classes beyond or distinct from standard high school curricula, aimed particularly at advanced high school students. These curricula would be provided to magnet-type programs across the country, and could perhaps be supported by NSF-funded training programs specifically for teachers in these distinctive programs. Many schools offer versions of Multivariable Calculus, for instance, but in our experience these classes usually compare poorly to college courses on the same topic; these high school versions frequently appear to do a cursory survey of a field where most college courses would go considerably deeper. In addition, as described earlier, it is a tremendous burden on magnet teachers to produce their own curricula for these classes. NSF-backed sample curricula on subjects beyond the norm might provide a basis for how to conduct these courses well, would make it considerably easier to start up magnet programs with these classes, and would considerably reduce the burden on magnet teachers. Some courses amenable to this sort of treatment (mostly taken from longtime Magnet courses) include:
    - Genetics
    - Analysis of Algorithms
    - Multivariable Calculus
    - Discrete Mathematics
    - Materials Science
3. *Enrichment modules for standard classes.* Enrichment-based units studying areas outside the purview of standard curricula could be developed expressly for insertion into regular classes. (These might even be units borrowed from courses from proposal 2.) In particular, these shouldn't be topics that go *beyond* standard curricula, but rather enrichment topics with a significantly different focus. These units would be aimed at enriching general education, but -- more importantly -- providing inspiration for talented students within that pool to independently explore an area of interest to them.

    Some examples of such units from introductory discrete mathematics are modular arithmetic, efficiently counting the symmetries of a 3D object, and basic social network analysis. Such units could tie into computer science courses via programming a rudimentary analysis of a social network or implementations of various encryption algorithms. At this level it is not difficult to show students immediate applications of their work to, e.g., Facebook. Work with such immediate applications, we suggest, is likely to prompt a potential innovator to continue studying this field outside of the classroom.

4. *Professional teacher recruitment.* Improving overall teacher quality in STEM fields seems well beyond the reach of the NSF, though Arne Duncan appears interested in pursuing this goal. It is still possible, however, for the NSF to have a positive impact on the situation by providing one-year fellowships for Ph.D. STEM professionals to teach in magnet programs. Such a fellowship could be attractive in much the same way as positions as NSF rotators are or the AAAS media fellowship is. In particular, curricular freedom and the quality of the students would attract potential teachers. Of the thousands of Ph.D.s produced in any given STEM field each year, some of them will in fact be competent teachers, and we should seek to draw on this pool of talent. One advantage of this approach is that a teacher excited about a topic of interest to her gives a perspective on modern scientists far more accurate than that provided by American cultural expectations. In addition, teachers holding doctorates, and especially younger postdocs, already set an excellent role model for students who could be attracted to pursue similarly advanced degrees. All of these mesh particularly well with magnet-type programs, which frequently grant their teachers unusual flexibility and provide teachers with unusually capable students.
5. *Online research-like experiences.* Educationally isolated students could benefit from a collaborative, research-like experience that takes place during the school year but is not geographically based. Such a program could be administered over the web, perhaps as follows. A set of data-intensive scientific problems would be introduced, with links given to background materials at both the popular and professional levels. Ideally, these would be problems for which real-world data has already been collected, but for which additional information can be gathered by doing (desktop) computer modeling. A panel of advanced undergraduates and graduate students would be formed for each problem, to provide guidance and motivation. For each problem, high-school participants would have access to an online forum or wiki where they would submit and debate proposals addressing the problem. A rating system for posts would keep track of the quality of the contributions of each student. Then, a proposal would be chosen from the forum either by popular vote or by the panel. This would be followed by a phase when high-school students would write or, with the help of existing tools, further develop software to attack the chosen problem in an open-source style. Existing data could be provided for participant use. For examples of other online classroom type experiences, see EPGY[15] and AoPS[16].
6. *Summer program pipeline.* The primary limitation of many summer programs is their limited ability to appeal to underprivileged students; besides a number of cultural barriers, for many of these students, simply leaving home for extended periods is an unusual and difficult step. A possible way of alleviating this problem is to create a sort of pipeline, with programs aimed at talented but underserved students at the middle school age range, with the goal of preparing them for the more advanced programs in high school. The Art of Problem Solving Foundation is investigating possible ways to run such a program with contributor Daniel Zaharopol.
7. *Virtual advanced labs.* The video game company Digital Radiance, a part of the HudsonAlpha Institute for Biotechnology in Huntsville, Alabama, constructed a video game based on a lab on recombinant DNA, which would cost about $1000 to perform in real life. When they tested it (complete with a comic-book story line) on a class of 100 regular high school students, three students were able to successfully complete the lab in an hour. Digital Radiance has plans to create dozens of virtual labs in various areas of science and offer them to high schools

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15. The Education Program for Gifted Youth, offered by Stanford University. http://epgy.stanford.edu/
16. Art of Problem Solving, http://www.artofproblemsolving.com/

for free for a few years. Surprisingly, this lab was programmed by a few college and high school interns, none of whom had previous 3-D graphics experience; the interns were all local, but the company is trying to expand. This type of program may have potential, both for recognizing talented students and for providing them virtual lab "facilities" and activities beyond what their school can offer. Perhaps the NSF could partner with technology companies to offer such opportunities.

As a final note, these proposals constitute *examples* of the sort of creative approaches one can take to solving the problems of STEM education. These examples are intended to demonstrate that a funded NSF call for proposals will get a wide variety of creative, original ideas with considerable potential.