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A DoD Perspective on STEM Education

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Abstract

The US Department of Defense (DoD) relies on science and engineering researchers to develop the technologies that provide the leading military capabilities for national security. We find that the current national production rate of scientists and engineers is sufficient to provide an adequate supply of scientists and engineers for the DoD research and engineering enterprise into the future. We advocate a need for DoD to recruit the top scientists and engineers into careers and endeavors that support defense capabilities, and that DoD recruit in those fields that best provide for future needs and capabilities. Based on the strategic guidance and the DoD S&T priorities, we make some suggestions as to strategic areas for DoD science and engineering recruitment.

Key words: STEM strategy, top talent, defense critical technologies, knowledge base

Introduction

In order to provide for the continued defense against the many new and varied threats, the US Department of Defense (DoD) is going to need new technologies and new capabilities for national security. Who is going to develop the future technologies for the US Department of Defense? Technologies based on scientific principles have enabled the US to dominate in military and economic prowess for decades. But in the future, advanced commercial technologies will proliferate quickly, and global access to defense capabilities has expanded, challenging US dominance. The Department will need to continue to play a leadership role in the development and exploitation of technologies that provide for national security.

One of DoD's biggest concerns is over the recruitment of scientists and engineers to develop the technology solutions that will maintain our military supremacy well into the future. As a bulwark for the nation's defense, we not only need an adequate supply of scientists, technologists, engineers, and mathematicians to provide solutions for defense needs, but we need the nation's best resources to focus on defense issues[i]. Without adequate numbers and expertise in the future, the Department of Defense could find itself confronting adversaries who possess the superior technologies in their weapons and defense systems.

American technology developments of the past have served us well, and are a large part of why the United States can boast the world's best and strongest military, as described in the US Defense Strategic Guidance (1). The US continues to dominate the world's science and technology (S&T) landscape, and our defense S&T enterprise continues to provide the systems that give us the advantage in operations throughout the world (2).

The problem relates to the future.

Background

Many warn that the nation's supply of people educated in science, technology, engineering, and mathematics (STEM) will be less than needed or desirable (3). They point to fewer doctorates in STEM fields[ii], less intensive STEM education in K-12 grades (4), and increasing global competition for STEM personnel (5). Others point to the fact that an increasing percentage of the graduates in STEM fields in the US are foreign-born (6), and thus are not available to work on classified or sensitive projects until they attain naturalized US citizenship.

But, in addition to the supply issue, the Department needs to recruit the best of those STEM-educated personnel to careers in defense science. The Department of Defense needs the best and brightest, because defense problems are among the most difficult science problems, and because the US defense systems need to be superior to adversary systems, for example, in the area of cyberdefense (7). In particular, DoD systems need to be able to defeat mainstay commercial technologies converted to weapons or asymmetric capabilities[iii]. Accordingly, the Department of Defense needs to engage the best STEM personnel from the global marketplace of researchers and engineers.

In addition, the Department of Defense requires a supply of researchers and engineers with expertise in fields that are not necessarily important to commercial technology. The Department must not only be concerned with the supply and demand of research and engineering personnel, but also the fields in which people are trained and maintain expertise.

The Department has a STEM strategy, codified in a document published in 2009 (8). The strategy includes provisions to inspire potential recruits, increase workforce development, recruit top talent, and deliver results using specific programs. There is a DoD STEM Executive Board to help guide and coordinate programs (9). Those programs oriented to STEM development in DoD are funded at about $150M per year; details for FY2010, as reported by a Government Accountability Office (GAO) report, are shown in Figure 1 (10). The GAO report calls for greater strategic planning to coordinate programs and reduce overlap across agencies, including DoD.

We posit that a viable human resources strategy for the Department of Defense research and engineering enterprise involves three major objectives:

1. Ensure that there is a sufficient pool of STEM-educated people from which defense researchers and technologists can be drawn;

2. Recruit the best and brightest into the defense research and engineering domains, as early as possible in their careers;

3. Ensure that the technical defense-critical areas are covered.

We next discuss DoD approaches to achieving each of these goals.

The supply side

There were an estimated 1.4 million researchers in the US in 2008 with about 4% annual growth rate between 1995 and 2002 (11). Since 2002, the growth rate has averaged 1% (11). There are a similar number of engineers in the US (some of whom may be counted as researchers), e.g., around 1.5 million[iv].

All told in 2009 the US graduated around 500,000 Bachelor's students in science and engineering (S&E) fields (12), and produced 41,000 PhDs in these fields (13). Engineering produces around 70,000 bachelor's degrees per year (12) and 8,000 PhDs (13). If all graduates pursued careers in S&E, with no attrition, then one might expect a national S&E workforce of around a 15 million, of whom 2 million would be engineers[v], with very approximately 11% having doctoral degrees. Of course, many graduates pursue other career paths either upon graduation or later in their careers[vi]. Clearly, retention is much higher among engineers than other STEM fields, reflecting labor demand and transportability of degrees.

Around 33% of the S&E PhDs are foreign nationals, on temporary visas in the US, although in engineering fields, more than half of the awarded PhDs are to students on temporary visas (14). Due to their visa status, they have had to prove that they intend to return home after their studies (15), or after a possible "practical training" as a postdoc in the US[vii]. In the past, many have ended up staying in the US (16), and some go on to achieve US citizenship and some even end up working in the DoD research and engineering enterprise.

Many believe that the US production rate of STEM-educated personnel is not sufficient. Indeed, the President's Council of Advisors on Science and Technology (PCAST) predict a need for one million additional STEM graduates, over current production rates, over the next decade (17). From 2008 to 2010 in the fields of computer science and

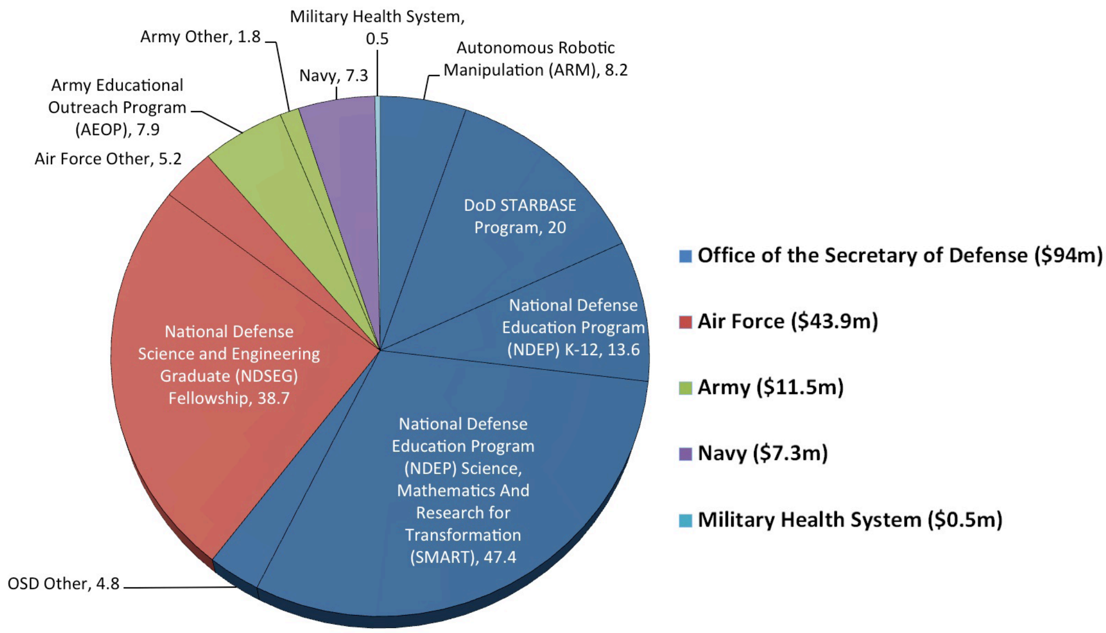

Figure 1: Data from GAO report "Science, technology, engineering, and mathematics education strategic planning needed to better manage overlapping programs across multiple agencies," Appendix II: List of STEM Education Programs with Fiscal Year 2010 Obligations (10).

engineering, PhDs awarded in the US fell by 7% and 4%, respectively (18).

From a DoD perspective, current production rates should suffice for defense needs, albeit there might be shortages in particular subfields. If the production rate is increased, then DoD would have a greater base from which to recruit, which would potentially improve the quality of the top talent. However, if the increased production is drawn from a pool of students that are at the average level or below, then the distribution of top talent will remain the same, and the quality of the desirable DoD STEM personnel would be unaffected.

Again from a DoD perspective, US citizens provide a more desirable pool of recruits than foreign nationals, because they can generally obtain security clearances and work on defense systems that require classified channels. Even when research and engineering does not require security clearances, regulations make it desirable that recruits are US persons, meaning that they are either citizens or have US permanent residency (a so-called "green card") (19).

However, the path from a temporary visa to permanent residency to US citizenship is long and convoluted. The process to permanent residency and citizenship can take anywhere from a year or two to decades[viii] which diminishes DoD's pool of available talent to work on significant DoD research and engineering issues. It is therefore in DoD's interest that US citizens (or people who intend to become citizens) are in the STEM education pipeline, especially in undergraduate and graduate educational programs.

But, the same caveat applies: that any increased production of US citizen STEM personnel must be drawn from a distribution that includes top talent, as opposed to merely drawing from a pool without top talent.

To expedite the transition from temporary visa to permanent residency, there have been suggestions that doctorates from accredited graduate programs be given rapid consideration for permanent residency upon graduation (20). Lindsey Lowell points out that this might create unintended incentives for immigration and lesser-quality PhDs (21). In this regard, such a policy would have a limited benefit to DoD. It would make some high-caliber awardees of PhDs more suitable for involvement with DoD research and engineering endeavors, but might also increase supply without appreciably increasing quality.

Vivek Wahdwa points out that many of these foreign national graduates now have opportunities in their home country (22). Whereas in previous eras they were highly motivated to remain in the US, they now might have intentions to eventually return home. Based on survey data, he believes that many will serve postdocs in the US, gaining "practical training" experience, and then join multinational corporations, state-run industries, or other jobs in their country of origin (23).

Either way, DoD is interested in assuring that the pool of STEM graduates, both citizens and permanent residents, is sufficient to supply top talent to DoD research and engineering. Current production rates far exceed the number required to sustain 1.4 million STEM personnel in the country; indeed, some have noted a booming supply of STEM skills (24). Thus DoD should be able to find sufficient numbers of highly qualified STEM graduates to sustain current numbers. Similarly, the number of engineers in the country is more than sufficient for DoD's purposes, although competition with commercial industry is more keen, based on the numbers. Thus, while it may be good public policy to increase the number of STEM graduates in the country, the Department of Defense has a more parochial interest of increasing the pool of top graduates in specific fields from which DoD can recruit researchers and engineers.

The Demand Side

Currently, DoD accounts for around 16% of all research and development expenditures in the US (based on R&D funding forecasts, which includes R&D investments by multinational corporations that are principally based in the US)[ix]. It is thus reasonable to assume that DoD employs, directly or indirectly, around 16% of the active R&D workforce. Therefore, the estimate is that DoD has around 300,000 to 350,000 personnel in the research and engineering enterprise (which includes both researchers and engineering personnel), around half of whom are engineers[x]. One can argue that the Department requires a greater number of STEM personnel, or that the enterprise should be reorganized, or that it needs to be made more efficient, but given current budget constraints DoD is not likely to grow the size of the workforce any time soon. The DoD R&D budget will support very roughly a workforce of 325,000.

DoD needs programs that ensure that they can actually attract and retain the best and brightest graduates into careers that support DoD research and engineering. We thus turn to the issues associated with recruitment, and creating a demand for DoD STEM personnel.

DoD recruits US citizens and permanent residents with an interest in defense science. Since interests are established early in ones career, it is important to understand the motivations for students to pursue degrees and ultimately careers in STEM fields.

While economics is certainly important, interest levels are probably even more important. The national focus on K-12 STEM education is, in part, a reflection that interest in science and engineering is often rooted in early experiences (25). When negative perceptions are conveyed at a young age, students are likely to turn to other pursuits. Conversely, when public awareness of science and technology endeavors is high, young people often respond[xi]. Defense science thus competes in the marketplace of ideas with medical sciences, environmental sciences, and video game technology. To the extent that DoD can promulgate the understanding that defense science and technology involves cutting-edge "cool" science, it can compete effectively (26). Indeed, science concepts and fundamental defense science issues often overlap. However, DoD's need to keep cutting-edge systems development secret undercuts efforts to inspire pre-college youth with the challenges of defense technology endeavors[xii].

Even when US students develop interest in fields that can lead to defense science, they must still compete for a limited number of available slots in colleges and graduate schools. The US Department of Defense would likely prefer that colleges and universities give preference to US citizens, permanent residents, or those intending on becoming US citizens, and to focus on certain desirable fields. But colleges and universities admit students largely based on academic merit, and draw from an international pool[xiii]. Although DoD can influence selections by funding scholarships and fellowships, the independence of the university selection processes is important for overall national goals.

As a result, candidates from the US are competing for limited numbers of slots against foreign nationals throughout the world. Concentrations of foreign nationals increase as we move up the academic education chain. For example, roughly 60% of all US PhDs in engineering are awarded to foreign nationals[xiv].

Economic incentives provide one part of the explanation. For candidates for fellowships and assistantships, annual stipends for graduate study in the US in STEM fields are typically in the range of $20,000 to $35,000[xv]. However, for US persons not subject to employment restrictions, a similarly talented Bachelor's or Master's recipient can often earn $50,000 or $60,000 at a corporate job, and even more in the engineering fields (27). The conclusion is that in certain fields, especially engineering, the earning differential between graduate study and employment is too large to incentivize continued studies. This is particularly true when you consider that the top Bachelor's graduates can command good salaries and rapid advancement in a company, compared to a stagnant and relatively low stipend, which, upon award of a doctorate, does not appreciably increase their earning potential. Accordingly, US persons pursue graduate studies only if they are highly committed to a research program, and much less motivated by financial considerations.

Foreign nationals, however, are generally not allowed to work outside of the university during the academic year (28), and the stipend often appears quite attractive. The American stipends appear attractive compared to competing opportunities (e.g., employment opportunities at home, or stipends at Asian or European schools) and so American graduate programs are highly desirable, if extremely competitive. Because foreign nationals are focused on their degree program without external work distractions, the best trained doctoral graduates are often the foreign students. This is a disadvantage for DoD, to the extent that capable American students are dissuaded and displaced from pursuing graduate degree programs in needed STEM fields.

A successful way for DoD to recruit US persons into defense work in STEM fields is through scholarship and fellowship programs, such as the SMART program[xvi]. This program, funded at $47M in FY12, provides tuition, expenses, and substantial stipends for either undergraduate or graduate work, in exchange for a commitment to pursue, for an equivalent number of years, direct employment with the US government in a related defense laboratory or agency. Stipends range from $25,000 to $41,000, on top of tuition and certain expenses. Combined with a guaranteed job upon graduation, the SMART program can (and has been) successfully recruiting high-caliber US students[xvii]. The work commitment after graduation is not currently considered a disadvantage, due to the economic environment. This could change in the future as undergraduates find their intention to continue graduate work interrupted by the years of service commitment, and more importantly, when employment prospects change or the student's interests change. Further, there may be policy, social and legal issues that the student should learn in addition to the chosen science field, and these could expand the options and interests that the student might wish to pursue. Thus, SMART is only one portion: DoD needs to recruit STEM personnel direct from fresh graduates in addition to those who are well into their careers.

Still, the total number of US persons earning doctorates in STEM fields over the past decade has continued to increase, with a slight decline in 2010, and provides a pool from which DoD can recruit expert defense science workers (29). Much of the increase is in the biomedical sciences area, but other areas are increasing as well (29). Further, DoD's demand for scientists and engineers are generally fulfilled because the problem sets in defense science are among the most interesting and compelling of human research endeavors. The nature of human interactions, and how to defend against attacks such as threats from terrorism or aggression, are among the most satisfying activities that a researcher can conduct[xviii].

Due to the demographics of the workforce, the Department of Defense expects large numbers of retirements of scientists and researchers, both at government labs, and in the defense industrial base, over the next decade (30). Of course, the recession that began in 2008 has impacted some worker's retirement accounts, and has had the effect of inducing delayed retirements. It remains to be seen whether this actually changes the statistics of DoD STEM retirements. Moreover, the government labs, and to some extent, industry, are populated with scientists who have plenty of practical experience, but less formal training. For example, in 2008 the Institute for Defense Analysis reported that about 10% of DoD's S&E personnel have doctorate degrees (30). Accordingly, one might hope to replace retirees with personnel that have a greater percentage of advanced degrees, to compensate for the relatively less practical experience.

Nuclear Weapons Technology	Anti-ballistic Missile Systems	Chemical Systems Technology
Space Satellite Systems	Information Exploitation Systems	Detection, Warning and Identification Systems
Cyber Systems, national-scale	Biological Weapons and Defense Systems Technology	Directed and Kinetic Energy Systems Technology
Weapons Effects and Counter-Measures	Information Warfare	Power Systems

Exhibit 1: Critical Non-Commercial Defense Technologies

When all is taken together, we can assume that DoD is in need of recruiting something like 10,000 to 20,000 STEM graduates into DoD research and engineering careers per year, and to retain and/or improve the quality of the workforce already engaged in the enterprise[xix]. Current production levels are sufficient, and with programs such as SMART, it should be possible to recruit sufficient numbers. However, acquiring top quality researchers, and in the right fields, is not straightforward. Compensation levels have to reflect the competitive landscape in order to acquire the right people. Recruits also need to learn a broad spectrum of skills beyond science, including policy, social, legal, and ethics topics. Most importantly, the areas of greatest importance to DoD need to be "covered," in the sense that the knowledge base of essential information is not lost nor neglected.

The knowledge base issue

We classify DoD's need for scientists and engineers into three groups:

1. Experts in certain critical fields and systems required for national security, but generally not important to commercial or civilian endeavors. The expertise is not likely to be obtained outside of defense science. Experts in nuclear weapons technology would be an example of this class.

2. Experts in fields and systems that are anticipated to be important for defense systems in the future. Often, basic physics, chemistry, electronics, biology, or computer technology is involved. Sometimes, but not always, these technologies have dual-use applications. Radar technology might be an example of this class.

3. Generalists or scientists who are experts in fields that have no obvious immediate application area, but are important because we do not know what the future will bring. DoD needs to cover areas that are considered active, but have not matured to a point where defense applications are apparent. Synthetic biology might be such an example.

Each group is critical, and DoD needs access to people in each group.

For the first area, DoD has a responsibility to maintain expertise in areas that are critical to national defense, but for which the commercial marketplace will not drive an adequate supply. For example, there is very little call for nuclear weapons experts in the civilian world, but the US must maintain a cadre of high caliber scientists with knowledge and expertise in the development, maintenance, and operations of advanced nuclear weapons. In a similar vein, advanced space satellite systems, offensive cyber weapons, and anti-ballistic missile systems, are among a host of defense-specialized technologies that are not likely to arise or be supported outside of a defense research and engineering enterprise. We show a list of suggested "critical non-commercial technologies" in Exhibit 1, but we acknowledge that this list is likely incomplete. Further, DoD needs to regularly revisit the list, to ensure that it accounts for new technology developments.

Priorities	Physics	Electronics	Information Theory	Chem–Bio	Mathematics	Engineering
Data to Decisions		Detection, Secure Communications, Microelectronics	Algorithms, Sensors, Analytic Approaches, User-Interfaces		Uncertainty Reasoning	
Engineered Resilient Systems	Systems analysis, mechanics	EDA, Electronics simulation, Trusted Systems		Materials science for 3D printing	Modeling 3D Structures, Partial Differential Eq., Computational Methods	Modeling, Simulations, Systems Engineering, Manufacturing
Cyber Operations	Modem technology	Communications, Networks	Info security		Encryption, Information theory	ECE, EE Disciplines
Electronic Warfare / Electronic Protection	EM Propagation	RF Microelectronics	Protocols	Neurotechnology	Encryption, Number theory	ECE, EE disicplines
Combating Weapons of Mass Destruction	Nuclear Technology, Detection		Attribution	Detection, Dispersion Technologies		
Autonomy		Micro/Nano, Sensors	Automation, Algorithms, Sensing		Pattern Analysis	Control Dynamics, Mech Engineering
Human Systems		Man/Machine Interfaces	Cognitive Reasoning, AI, Graphical Models	Neurobiology, Neurotechnology, Psychophysics	Complex Systems Analysis	

Exhibit 2A: Science and Technology (S&T) Priorities for Fiscal Years 2013-17 Planning

Maintaining expertise in these areas includes the requirement of education and training in the relevant technologies. In many cases, federally-funded research and development centers (FFRDCs) are responsible for maintaining US expertise in these areas, and ensuring the supply of that expertise through internal training (31). In other cases, the US maintains national laboratories, or service laboratories, where scientists and experts conduct work related to the areas of required expertise. Internal or specialized training is also required for government laboratory personnel. There is controversy from for-profit service industries that the FFRDCs and government laboratories sometimes pose unfair competition, and provide less efficient services (32), but the mission of training and maintaining special expertise in critical areas cannot be left to private industry alone.

In spite of their in-house training efforts, in order to maintain the expertise, the laboratories and centers will still have to recruit from a supply of STEM-educated personnel who have certain prerequisites as well as interest in the topic areas.

The second category involves more general fields. DoD must be able to recruit experts in those areas that will be important for national defense of the future. By looking at current research and engineering priorities, we can surmise that certain science areas will be important now and in the future, and this can guide investments, such as the SMART program, in acquiring the right kinds of fields. Exhibit 2A shows fields mapped to the "Science and Technology Priorities" that were designated by the Secretary of Defense in the spring of 2011 (33). Not sur-

Aeronautical and Astronautical Engineering	Electrical Engineering	Naval Architecture and Ocean Engineering
Biosciences	Geosciences	Nuclear Engineering
Chemical Engineering	Industrial and Systems Engineering (technical tracks only)	Oceanography
Chemistry	Information Sciences	Operations Research (technical tracks only)
Civil Engineering	Materials Science and Engineering	Physics
Cognitive, Neural, and Behavioral Sciences	Mathematics	
Computer and Computational Sciences	Mechanical Engineering	

Exhibit 2B: SMART Scholar for Service Program: Suggested Application Majors

prisingly, we find that information technologies, sensors, and chem/bio areas are particularly important to DoD. Mathematics is also prominent, although we are talking about college mathematics skills, and not necessarily advanced research mathematics. Exhibit 2B lists the fields that the SMART program names as being of significant DoD interest (34). Most of these areas line up well with the fields derived from the priorities (Exhibit 2A), but we note that there are some differences.

Some would say that these differences reflect a gradual process of adjusting to the new realities of the defense environment. The DoD S&T priorities may require multiple years for scientists and institutions to re-vector their efforts. In that regard, changes to the S&T priorities, or changes in the defense posture, will necessarily increase inefficiencies in utilization of S&T personnel as researchers are redeployed. Changes involve a learning curve, with training, or recruiting researchers in new domains, while warehousing or deprecating old fields.

But some of the uncertainty in the designation of fields that are important for DoD in the future reflects uncertainty about the future. The uncertainty is caused by disruptive changes that can occur, especially in the technology realm, and also due to the fact that one is dealing with dynamic adversaries, who are able to target gaps in capabilities. Thus, while our S&T priorities are important, there are many other areas that cannot be neglected. For these areas, DoD needs a certain amount of "coverage" in order to be able to maintain cognizance of science and technology progress and potential implications for defense. As a set of examples, Exhibit 3 lists some emerging "hot" science areas that the US Department of Defense has noted as areas that require monitoring for future breakthroughs that might occur[xx]. For most such areas, the current supply is sufficient for defense needs, since there is hardly a field of science and technology in which the US does not participate. The knowledge of the fields in which to recruit, and how to organize those recruits, is a nontrivial business of the DoD Research and Engineering enterprise. Not all the fields need necessarily be covered by government employees, as research grants and contracts can suffice to maintain a presence in certain fields. However, good global connections and communication patterns must be established so that DoD can take advantage of the talent available for tracking and investing in emerging or disruptive opportunities.

Summary

The Department of Defense needs to recruit the best and brightest scientists and engineers in the right fields to provide the technologies for national security in the future. The supply of talent is not lacking, nor is our ability to draw upon that talent. The main difficulty lies with knowing what fields to draw upon, and how to engage with the personnel in the entire defense S&T enterprise in an efficient and stimulating way. The pace of change, the globalization of research, and the pool of international graduates in STEM fields pose challenges for DoD, which must be addressed through timely changes of practices and policies.

Synthetic Biology involves modifying living cells (typically bacteria) to produce novel substances, such as bio-fuels, bio-sensors, improved vaccines, and high strength materials.	***Novel Engineered Materials*** encompasses superconductors, metamaterials, plasmonics, and spintronics, among other materials, that can provide fluid-repellant coatings, yield self-healing composites, improve energy efficiency, improve antennas and detectors, and greatly increase computational capabilities.
Quantum Information Science uses quantum mechanics to perform otherwise intractable numerical calculations, provide ultra-secure communications and solution possibilities to certain important problems, and enable an ability to simulate exotic materials.	***Human Behavior Modeling*** of individuals, groups, and nations is intended to enhance strategic and tactical decision making, improve immersive training and mission rehearsal, and facilitate cross-cultural coalition building.
Cognitive Neuroscience, the study of how the brain functions, provides a deeper understanding of human learning and decision-making, which can lead to improvements of performance under stress and to cures to the effects of war trauma.	***Nanoscience***, the study and manipulation of the radically different material properties that emerge at the nano-scale, makes possible new classes of electronics and sensors, chemical catalysts, high strength materials, and energetic materials.

Exhibit 3: Emerging Technologies that Could Form the Next Generation of Dominant Military Capabilities in the Next Decade

We have suggested a number of fields and directions, based on the defense strategic guidance, the S&T priorities, and fundamental science areas of interest. We've also suggested a tiered strategy of recruitment of specialists in unique areas, specialists in targeted areas, and access to a wide pool of generalists. The current structure of the enterprise and the fields of specialization have developed over time and, while they continue to serve us well today, may require adjustments in the ever-changing environment of science and technology.

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Competing interests

The authors declare that they have no competing interests.

Notes

i. As indicated by: Civilian human capital strategic plan 2006 - 2010 [Internet]. Arlington: US Department of Defense; 2005 Sep 3 [cited 2012 Jul 19]. Available from: http://www.cpms.osd.mil/ASSETS/A48A22FD8C0347FCAF182758F283A450/DoD-CivilianHumanCapitalStrategicPlan2006-2010.pdf.

ii. For example, the reduction in PhDs awarded in engineering and other fields in 2010 of about 1% overall: Fiegener M. Number of doctorates awarded in the United States declined in 2010 [Internet]. Arlington: National Science Foundation, National Center for Science and engineering Statistics; 2011 Nov [cited 2012 Jul 19]. Available from: http://www.nsf.gov/statistics/infbrief/nsf12303/nsf12303.pdf.

iii. For example, an asymmetric threat of bio-weapons might be based on simple technology to disperse influenza pathogens. Thus DoD will need superior bio-defense capabilities. See: Keim PS, et al. Adaptations of avian flu virus are a cause for concern [Internet]. Washington: Science Magazine, American Association for the Advancement of Science; 2012 Jan 31 [cited 2012 Jul 19]. Available from: http://www.sciencemag.org/content/335/6069/660.full.

iv. This estimate is derived from data in: Architecture and engineering occupations [Internet]. Washington: Department of Labor Bureau of Labor Statistics; 2012 Mar 29 [cited 2012 Jul 19]. Available from: http://www.bls.gov/ooh/Architecture-and-Engineering/home.htm.

v. This figure assumes a 30-year active career.

vi. There are many non-research career paths where a solid STEM foundation is important.

vii. The F-1 visa permits up to 29 months of temporary employment in STEM fields, also known as Optional Practical Training (OPT). In FY2010 there were 92,000 temporary foreign workers participating in OPT. With a H1-B visa a temporary professional specialty worker can stay up to 6 years. See http://www.fas.org/sgp/crs/misc/R42530.pdf.

viii. To attain legal permanent resident status in the US foreign workers face a wait time of many years. However, those who possess extraordinary ability or higher degrees do not wait as long.

ix. The DoD R&D budget is around $70B of the national $430B. See the Batelle and R&D Magazine 2012 Global R&D Funding Forecast (http://battelle.org/docs/default-document-library/2012_global_forecast.pdf?sfvrsn=2).

x. That is, roughly 16% of the 1.4 million researchers in the nation.

xi. For example, NASA's Apollo program had this effect. Then-NASA Administrator, at the 40th anniversary of the Apollo 11 landing, said: "Apollo inspired a generation of Americans – and other young people around the world – to study mathematics and science and pursue careers in aerospace-related fields." http://www.nasa.gov/pdf/372319main_Bolden_NASM_speech.pdf.

xii. Stealth technology was kept secret by the US for a number of years before becoming public. For example, the F-117A Nighthawk was started in the late 1970s but wasn't acknowledged until a decade later.

xiii. For example, see the undergraduate admission statistics for Harvard (http://www.admissions.college.harvard.edu/apply/statistics.html) and Yale (http://admissions.yale.edu/sites/default/files/Yale%20Class%20of%202015%20Profile.pdf).

xiv. That is, persons who are neither citizens nor permanent residents. http://www.nsf.gov/statistics/seind12/append/c2/at02-28.pdf.

xv. For instance, see the graduate stipends data for Stanford (http://vpge.stanford.edu/funding/vpge-fellowships.html) and UC Berkeley (http://grad.berkeley.edu/financial/deadlines.shtml#graddiv).

xvi. See the SMART Scholarship For Service program description at: http://smart.asee.org/.

xvii. Since 2005, 430 young scientists and engineers have been transitioned into DoD through the SMART program (see page 10, http://www.defenseinnovationmarketplace.mil/resources/Lemnois_041712.pdf).

xviii. Many defense science projects are cutting-edge (http://www.darpa.mil/NewsEvents/Releases/Releases_2012.aspx).

xix. Again, this assumes a 30-year active career.

xx. These areas were designated by Dr. Robin Staffin. Statement testimony of the honorable Zachary J. Lemnios [Internet]. Washington: US House of Representatives Committee on Armed Services, Subcommittee on Emerging Threats and Capabilities; 2012 Feb 29 [cited 2012 Jul 19] 6-7. Available from: http://www.defenseinnovationmarketplace.mil/resources/Lemnios_Testimony_2013.pdf.

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