# Addressing the National Need for Increasing the Domestic PhD Yield in Computer Science

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## 1. Introduction

The demand for PhD's in computer science (CS) in the US continues to outpace the supply. Both industry and academia struggle to fill positions. Since 2014, approximately 2000 CS PhDs have been awarded annually and about 60% of new PhD graduates take jobs in industry [ZwBi19]. The rapid growth in undergraduate CS enrollments during the last decade has significantly increased the number of open faculty positions at academic institutions, but has so far not led to an increase in the number of PhDs graduated.

Historically, US PhD programs have relied heavily on international students. Figure 1 shows the number of CS PhDs awarded annually to domestic and international students since 1985. The percentage of domestic PhD students graduating decreased from 69% in 1985 to 37% in 2018.
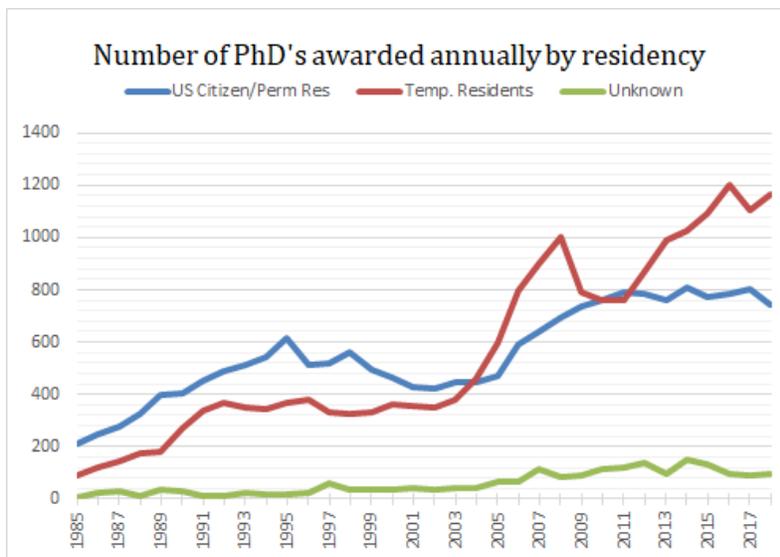


**Figure 1:** Number of PhD's recipients in Computer and Information Science
by residency (1985-2018). Source: NCSES

The reliance on international students to drive innovation and leadership in computing research in the US has become unstable as international students increasingly face obstacles or disincentives to study in the US, and an increasing number return home to attractive opportunities after graduation from a US university.  Moreover, some areas of computing have security implications that make positions in those areas inaccessible to non-US nationals.  **The continuing demand for PhDs in computer science combined with this instability of international student participation requires bold action to increase the number of domestic students completing a PhD in computer science.**

This report proposes significant ways that government, industry, and academia can take action to engage domestic students to enter PhD programs and retain them through graduation.  This includes increasing opportunities and funding for undergraduate research, articulating the value of a research career, increasing the number of national fellowships available for domestic students, creating more and more varied pathways into PhD programs, engaging students from admissions through PhD, and strengthening industry's role in increasing the number of PhDs in CS.

## 2.    Increase Undergraduate Research Participation

Many indicators suggest that undergraduate research experiences are effective in encouraging students to consider graduate studies [NAS17, Wr20].  We make two broad recommendations for increasing undergraduate students' participation in research: (1) Expanding Funding for Undergraduate Research and (2) Expanding and Promoting Research Opportunities.

**Expanding Funding for Undergraduate Research**

As a competitive alternative to industry internships and to support students who must earn money, funding agencies should create new funding opportunities for undergraduate students and their mentors. The main federal funding source for undergraduate research in CS is NSF through its REU sites and REU supplement program.  Our recommendations include:

● Support departmental REU programs. REU supplements are available to PIs with existing NSF grants. This restriction means that many potentially excellent undergraduate research mentors are not eligible.  We recommend that NSF introduce departmentally managed REU programs supporting undergraduate research. Such a program can also involve faculty and student groups from other, possibly non-PhD granting institutions, with the goal of creating pipelines into PhD programs.

● Re-evaluate the structure of REU sites. NSF REU sites bring together a cohort of students to a single research site. Sites require a substantial amount of planning and oversight, and compensation for PIs and mentors is minimal.  We recommend increasing incentives for faculty and academic departments to organize and run REU sites.

● Support from other funding agencies.  With CS being at the core of most scientific advances, funding agencies (other than NSF) should reevaluate and expand undergraduate research opportunities for CS students in computing-driven fields.

● Support the launch of new and innovative undergraduate research opportunities. Government agencies should support academic departments to launch scalable research-supporting activities such as regional centers targeted at a research area of national interest.

**Expanding and Promoting Research Opportunities**

High undergraduate CS enrollments, large class sizes, and the resulting strain on faculty time have reduced faculty willingness to supervise undergraduate research [CaAdBi18].  High-paying jobs in industry for BS graduates continue to reduce student interest in graduate school.  Expanding research opportunities for undergraduates and communicating the value of a PhD is crucial for a strong, diverse, and inclusive

workforce of the future.  Building on the best practices described in recent CRA-E's report [AlHiK020], our recommendations include:

- **Lower the barrier to entry.**  Academic departments should centralize recruiting to make it easier for undergraduates to find and apply for research opportunities and help faculty to identify interested students.
- **Competitive compensation for undergraduate research.**  Research should not be an activity reserved for wealthy students.   Many CS students cannot afford to turn down a highly-paid industrial internship or well-paying part-time jobs.
- **Incentives for faculty.** Junior faculty need to receive "credit" for taking on research students, research mentoring should be valued for promotion and tenure, and faculty should receive reasonable financial compensation for summer mentoring efforts.
- **Increase departmental support**. The costs to faculty can be reduced by offering a departmental research methods course and training graduate students in mentoring undergraduates.
- **Strive for high quality research experiences.**  Students need to be appropriately challenged and receive good mentoring.
- **Celebrate achievements.** Student research involvement should be celebrated by the department through activities such as research poster sessions, highlights on the department website, awards, among others.

Finally, the community needs to redouble its efforts to communicate the value of a PhD to students (e.g., through presentations and sharing existing resources.) Research in computer science benefits society in many ways from advancing fundamental research to developing technologies that benefit our economy and society.  A PhD is the primary pathway to contributing to computing research and also offers tremendous opportunities for personal growth by developing skills in problem-solving, communication, and leadership.

## 3.  Create New Pathways into PhD programs

The recommended path to graduate school is to engage in research by the summer of the junior year both to develop a sense of what research entails and to prepare a strong graduate school application.  However, many students do not have an opportunity for a formative research experience.  Some students do not know by their junior year that they are interested in research, some do not have an opportunity to participate in research, some need to take a job after graduation, and some do not understand the value of graduate education.  This section describes a number of pathways having the potential to expand the pool of domestic students pursuing a PhD. These new pathways require support from government funding agencies and industry as academia implements them.

**Pathways for Undergraduates through a 4+R Program**
A 4+R program mirrors existing 4+1 programs in which students complete a BS and an MS in 5 years, but instead of taking courses toward an MS, students would dedicate their fifth year to gaining research experience before applying to a PhD program. Creating a 4+R program enables a student to pursue research and prepare for graduate work in their area of interest in the fifth year.  Financial support in the fifth year should be in the form of one-year fellowships for domestic students or RA/TA support.

**Pathways for MS Students**
Students who have had little or no research experience or are concerned about their success in a PhD program often pursue an MS degree.  Domestic MS students are an important group of potential PhD students. Academic departments should create effective pathways for MS students to enter the PhD program, including:

- Encourage MS students to engage with research groups and PhD students.
- Support research experiences for MS students by giving course credit.
- Identify strong domestic MS students and encourage them to consider a PhD.
- Have flexible policies allowing students to switch from an MS to the PhD track.
- Provide financial support for MS students pursuing research, especially for MS students doing research in the summer after their first year.

### Pathways for Students with Non-CS Backgrounds

Individuals with a non-CS background interested in a CS PhD generally have background gaps. Flexible models are needed to fill these gaps and prepare students for research.  These may include:
- A one-year non-degree program, using existing undergraduate courses, specifically targeted at developing CS background knowledge.
- On-line courses targeted at individuals with non-CS backgrounds. These courses could be created through an alliance between institutions.
- Academic departments should explore innovative ways to use the diverse non-CS backgrounds of students in their programs.

### Pathways for Students Returning from Industry
Graduate students with experience in industry are invaluable to the research community.  Partnerships that are mutually beneficial to industry and academia include:
- Providing employees a one-year leave for the first year in the graduate program, as is currently done by a number of government agencies.
- Allowing part-time employment to explore graduate school.
- Providing fellowships for students returning to graduate school from industry.
- Offering course credit for certain kinds of industry experience.
- Engaging students with industrial experience in some aspects of academic life such as staffing capstone experiences, software engineering courses, and mentoring of undergraduates.

## 4.   From Pathways to PhD
We make recommendations on three crucial ingredients for success in a PhD program: inclusive admission processes, an environment actively supporting retention, and fellowships and financial incentives.

### More inclusive PhD admission criteria
Current recruiting and admission processes and criteria may fail to recognize the potential of non-traditional applicants. More specifically, students who have not yet narrowed their areas of interest, do not have publications, or did not graduate from a well-known institution may be significantly disadvantaged. Academic departments may thus overlook students with tremendous potential [HaLi13]. Departments should examine their recruiting and admissions processes and ensure that faculty involved in making decisions are well-informed about the diversity of institutions and student backgrounds.  First year fellowships for domestic PhD students with strong academic background but lacking research experience will incentivize departments to broaden admissions criteria.

### Retention in PhD programs
A successful PhD pipeline includes more than recruiting and admission. Mentoring and attention to retention are equally important. While it is natural for some students to leave before completing their PhD, it is also important for academic departments to take interventions to help retain high-potential students.  To help improve retention, academic departments should provide:

- Broad data collection and analysis of student progress to understand challenges impacting retention and supporting effective regular feedback to students.
- Mentoring for PhD students that is responsive to their culture and background.
- Advocates for students to contact with problems and concerns, especially on advisor-related matters.

**Fellowships**
Increasing the pool of domestic PhD students must involve an increase in fellowships and other financial incentives. Our recommendations include:
- Increase the number and breadth of fellowships. In particular, create national 1-year fellowships for domestic students applying to graduate school with minimum research experience. The NSF Graduate Research Fellowships Program provides a small number of fellowships typically targeted at students with research experience.
- Institute a national program that forgives student debt for domestic students pursuing a PhD in computing fields. Such an effort can be viewed as a GI-Bill for strengthening the domestic PhD pipeline.
- Fellowships should include opportunities for domestic MS students and also support students switching from MS to PhD programs.

## 5. Strengthen Industry's Role

Industry hires about 60% of the computer science PhDs produced in the US and over 90% of computer science BS recipients [ZwBi19]. The increase in open faculty positions due to the surge in CS undergrad enrollment has created a competitive relationship. The health of the PhD production in CS should be driven by a more collaborative effort involving academia, industry, and government research labs. We make several recommendations for building these stronger relationships.

**Build a Graduate Fellowship Consortium**
A number of companies, including Google, Microsoft, Facebook, and IBM, offer PhD Fellowship programs. These fellowships are often targeted at research areas relevant to the company. Building on the success of these models, industry should explore new and expanded fellowship programs that support the health of the domestic PhD yield. In particular, we recommend the development of a Fellowship Consortium led by companies that hire PhDs. Membership contributions would provide fellowships for PhD students and fund summer support for master's students to explore research. A professional organization such as CRA could assist in managing this effort.

**Support Employees Pursuing a PhD**
Employees returning to graduate school bring valuable experiences to academia. Industry should support such a career change through flexible and mutually beneficial arrangements. For example, allow employees to take a 1-year leave, as done by some government agencies, and allow working part-time. Combinations of such approaches can provide support making the transition to research easier. In addition, a Fellowship Consortium can provide special fellowships for returning students.

**Support Undergraduate Research**
Industry and government research labs should increase their support for undergraduate research. Undergraduate research experiences not only increase the interest in graduate school, but they increase persistence and provide teamwork and communication experiences. In particular, we recommend providing funding for REU programs run by national organizations like CRA-WP and to support REUs for

researchers already funded by industry. Summer internships should include students in industry research groups (as opposed to development groups) and fund related research done during the year.

## 6. Major Recommendations

In summary, our major recommendations are the following:

**For funding agencies**
- Explore creating a national program that forgives student debt for domestic students pursuing a computer science PhD.
- Fund departmental REU programs that increase the pool of qualified faculty mentors and build alliances between institutions.
- Fund CS departments to launch innovative and scalable undergraduate research-supporting activities.
- Increase the number and breadth of fellowships. In particular, create national 1-year fellowships for domestic students applying to graduate school with minimum research experience.
- Provide fellowship opportunities for MS students switching to a PhD program.

**For industry and government research labs**
- Build a Graduate Fellowship Consortium.
- Provide funding for summer research experiences for first year domestic MS students to increase interest in research and a PhD.
- Give employees a one-year leave for the first year in the graduate program, as done by a number of government agencies.
- Fund REU programs run by national organizations like CRA-WP and by academic departments.
- Provide REU supplements to researchers supported already through industry funding opportunities and provide micro-REU awards.

**For academia**
- Adopt and implement practices that expand undergraduate research opportunities as outlined in the CRA-E report *Best Practices for Expanding Pathways to Undergraduate CS Research.*
- Create and support new pathways into the PhD program that attract and support talented individuals who realize their research passion at a later stage in life.
- Provide financial support for MS students pursuing research and have flexible policies allowing switching from an MS to the PhD track.
- Explore innovative ways to leverage diverse non-CS backgrounds and industry experience in the PhD programs.
- Have broad data collection and analysis of student progress to understand challenges impacting retention and supporting effective regular feedback.

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## Acknowledgements