

SCIENCE EDUCATION

Increasing Persistence of College Students in STEM

Mark J. Graham,^{1,2} Jennifer Frederick,¹ Angela Byars-Winston,³ Anne-Barrie Hunter,⁴ Jo Handelsman^{1*}

A 2012 report by the President's Council of Advisors on Science and Technology (PCAST) predicts that the U.S. workforce will suffer a deficit of one million college graduates in science, technology, engineering, and mathematics (STEM) over the next decade (1). The report calls for addressing the shortfall by increasing retention of college students in STEM. But many academic leaders have not responded aggressively to workforce needs by implementing measures that increase retention. Some of this nonaction is likely due to lack of knowledge about proven retention strategies.

Here, we introduce a “persistence framework” that integrates evidence from psychology and education research into a guide for launching and evaluating initiatives aimed at increasing persistence of interested college students (2–5). We emphasize “persistence,” which focuses on student agency (6), rather than on the institutional perspective of “retention,” although the intended outcomes are the same. Most of the research we review was conducted in the United States, but the problem is not unique to one country, and the solutions are probably universal.

Persistence of more top students would address the projected STEM workforce deficit, while building a deeper, broader talent pool (1). Less than half of the three million students who enter U.S. colleges yearly intending to major in a STEM field persist in STEM until graduation (1). The exit rate is especially high for the so-called “underrepresented majority,” women, racial, and ethnic minorities who are underrepresented in STEM majors but collectively make up 68% of college students in the United States (7). For example, African-American students who intend to major in STEM switch to a non-STEM field before graduation twice as

often as white students (8). Such stark statistics invite a hard look at research and practice that bear on retention.

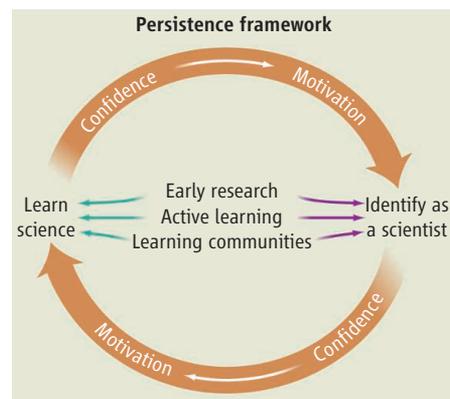
The concept of persistence originates in social and cognitive psychology as one manifestation of motivation (6). In education, motivation is viewed as a driver of student engagement. Among the important constructs underlying motivation is the powerful influence of confidence (i.e., self-efficacy), which is a requirement for persistence (9). Therefore, it is imperative that persistence efforts address motivation and confidence (see the figure).

The framework identifies learning and professional identification as determinants of persistence. Research demonstrates their importance in predicting student behavior (2, 4, 10), and both can be modulated by myriad interventions (7). Some of the most successful STEM retention initiatives pay careful attention to both elements (3). Moreover, both learning and professional identification increase confidence and, consequently, motivation, which in turn spur academic success and feeling like a scientist, thus creating mutually reinforcing experiences (see the figure). This contrasts with student reports of many current introductory STEM courses that obscure the subject, diminish students' confidence, and discourage them from becoming scientists (7). Although the conceptual elements are well established, unifying them into a single persistence framework for guiding STEM education is new.

Answering PCAST's call to increase STEM student retention requires widespread attention. Departments and institutions also need flexibility in the approaches they take and a look at working examples they can model. Because the framework unifies principles that may be implicit in even the most successful programs, we highlight a few intensively studied ones with quantifiable success (although many other successful models exist).

For African-American students and other underrepresented groups, the University of Maryland–Baltimore County Meyerhoff Scholars Program has dramatically increased student achievement, retention, and graduate

An evidence-based framework offers a guide for efforts to increase student persistence in STEM majors.



The Persistence Framework. Confidence is belief in one's own ability; motivation is intention to take action in pursuit of goals; learning is acquiring knowledge and skills; and professional identification is feeling like a scientist.

study in STEM fields. Of their 508 STEM majors between 1993 and 2006, Meyerhoff boasts 86% retention in STEM (3), twice the nationwide average for all students and more than four times the average retention for African-American students. Other programs such as the Biology Scholars Program at University of California, Berkeley (11), more broadly target gender, racial, and ethnic groups. Another approach is the peer-led Gateway Science Workshops at Northwestern University (12), which are open to all beginning STEM students. The Posse programs that focus on urban-schooled science students (1), and the LA-STEM and Howard Hughes Medical Institute (HHMI) Research Scholars Programs at Louisiana State University that focuses on promoting student diversity in STEM are other outstanding examples.

Such successful programs commonly use three interventions widely recognized for inspiring STEM students: (i) early research experiences, (ii) active learning in introductory courses, and (iii) membership in STEM learning communities (see the figure).

Early research experiences. Despite well-known benefits of research experience, most undergraduates are not offered research opportunities until late in college, after the critical period of attrition from STEM

¹Center for Scientific Teaching, Department of Molecular, Cellular and Developmental Biology, Yale University, New Haven, CT 06520, USA. ²Department of Psychiatry, School of Medicine, Yale University, New Haven, CT 06511, USA. ³Department of Medicine, School of Medicine and Public Health, University of Wisconsin, Madison, WI 53705, USA. ⁴Ethnography and Evaluation Research, University of Colorado, Boulder, CO 80309, USA.

*Corresponding author. E-mail: jo.handelsman@yale.edu

majors (13). Students who engage in research in the first 2 years of college are more likely to persist in STEM majors (14). Research experience is a powerful learning tool, engaging students and stimulating curiosity; and it naturally encourages professional identification because students are being scientists, not just studying products of other people's science.

The PCAST report recommends implementing research courses for all beginning undergraduates (1). Research courses provide students with the project ownership and intellectual challenges of empirical pursuit. At the same time, these courses use teaching time and materials efficiently by having student teams work on parallel problems that require similar techniques.

In research courses, students engage in authentic research—they design experiments, collect and analyze data, and sometimes make significant discoveries (15); thus, undergraduates in research courses experience the same dramatic gains in learning and positive attitudes toward science as those who conduct research in faculty laboratories (10, 16).

A variety of research courses have been implemented successfully at large and small institutions. Faculty who are understandably hesitant to accept inexperienced undergraduates into their research laboratories find research courses feasible and rewarding to teach. One is the multi-institutional HHMI–Science Education Alliance (SEA) PHAGES in which freshman discover new bacteriophages from soil (15). The University of Texas at Austin's Freshman Research Initiative demonstrates that research courses can also be cost-effective on a large scale when they replace traditional introductory lab courses. In the Austin model, faculty provide projects, derived from their own research, as the basis for student research projects in lab sections of 20 to 30 students.

Active learning in introductory courses. Many talented college students flee STEM majors because they find introductory courses uninspiring (7). This can be corrected by incorporating classroom teaching practices that engage students in the learning process, known as “active learning,” which has been shown to reduce STEM attrition (17). Active learning includes any activity in which every student must think, create, or solve a problem. For example, brief lectures interspersed with opportunities for students to reflect on or apply their own knowledge

PUTTING THE PERSISTENCE FRAMEWORK INTO ACTION

- (i) Faculty and instructional staff should teach undergraduate research courses, use active learning in introductory STEM courses, and encourage students to form learning communities;
- (ii) Students should be educated about the benefits of learning communities and supported to create their own;
- (iii) Departments should examine curricula and reward structures to incentivize effective teaching, and then align them to enable early research and active learning in introductory courses;
- (iv) Provosts, deans, and chairs should advocate for and dedicate resources to changing classroom practice by creating opportunities for instructors to learn new teaching techniques;
- (v) Public and private funding entities should apply the persistence framework to evaluation of new initiatives in STEM undergraduate education; and,
- (vi) Accreditation agencies should incorporate measurements of STEM persistence into their periodic institutional reviews.

induces active engagement in large lecture courses (18). Active learning improves understanding and retention of concepts and information (1), and it helps students identify as scientists because they participate in scientific thinking with peers who create a scientific community.

Faculty are often reluctant to try active learning because of lack of experience, so it is essential to provide training. Opportunities exist at many universities, professional societies, and in the National Academies Summer Institutes on Undergraduate Science Education, a national program that trains instructors in evidence-based instructional methods (19).

Membership in STEM learning communities. Learning communities are typically virtual or physical structures that provide gathering places or events that enable students to work with and learn from each other (12).

Forming learning communities often requires a small financial investment that produces substantial impacts on student achievement and persistence. Establishing learning communities can be as simple as ensuring that all students have access to a study group outside of class or providing an online environment where students can discuss course content. Learning communities can be constructed in tutoring centers where students congregate by course or discipline, science clubs, or science-based residential communities (12). All of these activities stimulate intellectual growth. Involvement with other students who are aspiring scientists also strengthens professional identity.

To ensure inclusion of all students in learning communities, attention must be paid to being impartial. Students from groups typically underrepresented in science are less likely to form study groups, may be unaware

of the academic benefits of group work outside of class, and confront unintentional biases that may make it challenging to break into established cliques (20). Instructors can reduce this tendency by confronting the issue in class and encouraging students to form and join inclusive groups.

Proven interventions exist, so now it is time for all stakeholders to contribute to increasing student persistence in STEM majors (see table). The elements of the persistence framework are universal and can be tailored for any classroom. In the United States, a concerted effort to implement evidence-based strategies will pay off by advancing the goal of having sufficient STEM college graduates to meet projected workforce needs.

References and Notes

1. PCAST, *Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics* (PCAST, Washington, DC, 2012).
2. M. Estrada, A. Woodcock, P. R. Hernandez, P. W. Schultz, *J. Educ. Psychol.* **103**, 206–222 (2011).
3. M. F. Summers, F. A. Hrabowski III, *Science* **311**, 1870–1871 (2006).
4. H. Thiry, S. L. Laursen, A.-B. Hunter, *J. Higher Educ.* **82**, 357–388 (2011).
5. A. Byars-Winston, B. Gutierrez, S. Topp, M. Carnes, *CBE Life Sci. Educ.* **10**, 357–367 (2011).
6. A. Bandura, *Am. Psychol.* **44**, 1175–1184 (1989).
7. E. Seymour, N. M. Hewitt, *Talking About Leaving* (Westview Press, Boulder, CO, 1997).
8. National Academy of Sciences, National Academy of Engineering, Institute of Medicine, *Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads* (National Academies Press, Washington, DC, 2011).
9. C. S. Dweck, *Am. Psychol.* **41**, 1040–1048 (1986).
10. D. Lopatto *et al.*, *Science* **322**, 684–685 (2008).
11. J. Matsui, R. Liu, C. M. Kane, *Cell Biol. Educ.* **2**, 117–121 (2003).
12. G. Light, M. Micari, *Making Scientists* (Harvard Univ. Press, Cambridge, MA, 2013).
13. S. H. Russell, M. P. Hancock, J. McCullough, *Science* **316**, 548–549 (2007).
14. B. A. Nagda, S. R. Gregerman, J. Jonides, W. Von Hippel, J. S. Lerner, *Rev. Higher Educ.* **22**, 55 (1998).
15. G. F. Hatfull *et al.*, *PLoS Genet.* **2**, e92 (2006).
16. A.-B. Hunter, S. L. Laursen, E. Seymour, *Sci. Educ.* **91**, 36–74 (2007).
17. D. C. Haak, J. HilleRisLambers, E. Pitre, S. Freeman, *Science* **332**, 1213–1216 (2011).
18. J. Handelsman, S. Miller, C. Pfund, *Scientific Teaching* (W. H. Freeman, New York, 2007).
19. C. Pfund *et al.*, *Science* **324**, 470–471 (2009).
20. C. A. Moss-Racusin, J. F. Dovidio, V. L. Brescoll, M. J. Graham, J. Handelsman, *Proc. Natl. Acad. Sci. U.S.A.* **109**, 16474–16479 (2012).

Acknowledgments: This work was supported by a grant to J.H. from the HHMI Professors Program and NIH Grant 1R13GM090574-01. We thank E. Baraban and J. Young for comments on an earlier version of this manuscript.