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Science education. Increasing persistence of college students in STEM

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Summary:

Integration of evidence from disparate fields of research generates a “persistence framework” to guide efforts to increase student persistence in STEM majors.

The recent report, “*Engage to Excel*,” issued by the President’s Council of Advisors on Science and Technology (PCAST), predicts that the United States workforce will suffer a deficit of one million college graduates in science, technology, engineering, and mathematics (STEM) fields over the next decade (1). The PCAST report calls for educators to address the shortfall by increasing retention of students in STEM fields. Nearly 60% of the three million students who enter college intending to major in a STEM field switch to non-STEM majors (1). Educators need guidelines to increase persistence of STEM students, but evidence and practice have not been synthesized into a single framework. This lack of cohesion is the consequence of student performance and behavior being studied in disparate fields of psychology and education that exhibit little apparent cross-fertilization or synthesis. Here we introduce a “persistence framework,” which integrates evidence from multiple fields into a cohesive guide for launching and evaluating initiatives aimed at increasing persistence of interested, talented students in STEM.

Many talented college students flee STEM majors because they find introductory courses uninspiring (2). Students who switch from STEM majors often cite as problematic the prevailing teaching practices, lack of conceptual learning, and the traditional “weed-out” mentality, which are intended to eliminate unsuitable candidates but create an unwelcoming environment that alienates successful and struggling students alike (2, 3). The students who

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do not persist in STEM despite interest and high performance create an attractive pool from which to draw more STEM graduates. The PCAST report observes that a 10% reduction in undergraduate STEM attrition would address almost three-quarters of the projected STEM workforce deficit, while simultaneously building a deeper, broader talent pool (1).

Successful retention programs have been implemented at some institutions, but efforts are still falling short, especially for the so-called “underrepresented majority” (4): that is, women and ethnic minorities, who are underrepresented in STEM majors but collectively comprise 68% of college students in the U.S. (1, 2, 4). For example, 82% of African American students who intend to major in STEM switch to a non-STEM field before graduation, compared to 67% of White and 56% of Asian populations (5). The starkness of these statistics invite a hard look at research and practice that bear on factors influencing persistence.

In light of current concern about employment opportunities for college graduates, it is puzzling that academic leaders have not responded to national workforce needs by implementing measures to increase retention of STEM students. Proven retention strategies may not be well known among academic leadership, and therefore we offer a persistence framework to simplify and unite the disparate research that bears on the issue (6–14). The framework highlights “persistence,” which focuses on student agency, rather than on the institutional perspective of “retention,” but the intended outcomes are the same.

Persistence framework.

The persistence framework is defined by learning, motivation, and professional identification (Fig. 1). Extensive research shows each as a determinant of student behavior (11, 15), but they emerge from the disparate fields of cognitive, educational, and vocational psychology (9–12). Although some interplay among the elements of the persistence framework has been recognized (16), the disjunction of these fields – reinforced by distinct lexicons, professional societies, and journals – has prevented the genesis of a unifying framework (17). Therefore, although the conceptual elements of the persistence framework are well established, their unification into a single framework is new.

The framework (Fig. 1) is both a blueprint and an evaluation rubric for STEM retention programs intended to guide educators to address all three elements without needing to either intuit or stumble upon them. But the framework is not prescriptive -- each element can be satisfied by myriad interventions (2), with the most impactful interventions addressing more than one element. It is striking that some of the most successful STEM retention initiatives pay careful attention to all three elements, providing practical models that illustrate the framework’s central tenets (13).

Application of the persistence framework.

The highest impact interventions are likely to be those that affect all three components of the persistence framework. For example, research experience affects student learning, motivation, and professional identification. Similarly, active learning and participation in learning communities, which are often studied for their value to one aspect student development, reach students at cognitive, emotional, and social levels. Not surprisingly, these cross-cutting practices dramatically increase persistence of STEM students who experience them early in college (18).

Early research experiences.

It is not news to most educators that research experiences (or design, in the case of engineering) enhance learning by requiring students to apply knowledge to analyze and solve problems (15, 19–22). But research experience also targets the other pillars of the persistence framework. Independent work, feelings of project ownership, the potential for original discovery, and effective feedback from an experienced advisor, which are inherent to a quality research experience, enhance *motivation* (15). Third, research groups provide undergraduates with the opportunity to be members of scientific communities. As students develop the intellectual skills necessary for conducting scientific research, their confidence increases (20, 23), and they begin to view themselves as scientists who are part of and contributors to a scientific community, thereby effecting *professional identification,* a key factor in student persistence in STEM (20, 24).

Despite the well-known effects of research experience, most undergraduates are not offered opportunities to participate in research until later in college, after the critical period when most attrition from STEM majors occurs (15, 23). Research experiences contribute to higher retention of all students, with particularly strong effects on members of groups underrepresented in STEM majors (15, 19, 25–28). Many of the students who might have accessed research experiences as juniors and seniors do not survive in STEM majors long enough to attain that opportunity, making early research experiences an important intervention to achieve a 10% increase in retention of STEM majors (18).

The PCAST report exhorts educators to engage students in research endeavors in the first two years of college (1). To contend with the logistical challenge of offering research experience to all students who intend to major in STEM fields, the report recommends implementation of research courses, which, like research experiences in faculty research laboratories, enhance student learning and attitudes toward science (15, 20, 29, 30). Research courses thrust students into the frontiers of science, providing them the rewards of designing experiments and making authentic scientific discoveries. Research courses can be cost-effective on a large scale when they replace traditional labs that often accompany introductory STEM courses, as demonstrated at the University of Texas at Austin *( ).*

Active learning in introductory courses.

Teaching practices that engage students actively, known as “active learning,” reduce STEM attrition. Numerous studies demonstrate that the benefits of active learning are manifold, especially in large lecture-based science and engineering courses. Active engagement bolsters student *learning*, retention, and graduation, and increases pursuit of advanced study when compared to traditionally taught comparison groups (2, 7, 8, 13, 31–33). Diverse active learning methods have these impacts (34), including peer instruction (35), small group discussion (36–38), “clickers” (38, 39), problem-based learning (40, 41), team-based learning (42), and weekly testing (43, 44). The impact of active learning has been measured with top-performing and academically weaker students (36, 38, 45), and at public, private, military, liberal arts, and technical institutions (29, 46).

The impact of active learning can be augmented by including content that illustrates the utility of scientific knowledge, which further engages students and *motivates* learning by engaging the habits of mind needed for scientific investigation (15) and providing immediate feedback from peers and instructors (47). Collaboration with other students to solve scientific problems or design challenges induces students to *identify* as members of a scientific community (48, 49).

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. Just as classroom group work strongly promotes learning, so does group activity outside the classroom (15). For example, within a study group the students hear course material presented in a variety of ways, increasing the likelihood that it will resonate with each student's own learning style and prior knowledge. Students *motivate* each other with encouragement, creating an expectation of success, which in turn increases the probability of success (50). Both students and faculty serve as role models in learning communities, generating a social structure that induces students to *identify* as scientists (51, 52), an element that is emerging as an essential driver of student choice (11, 16).

Establishing learning communities can be as simple as ensuring that all students have access to a study group outside of class or providing a course blog on which students can discuss course content. Learning communities can also be constructed through tutoring centers in which students can congregate by course or discipline; science clubs that organize events or trips; or science-based residential communities. In any organization of a learning community, attention must be paid to ensuring inclusion of all students as groups typically under-represented in science can find it more challenging to break into established cliques and may be unaware of the academic benefits of group work outside of class (51). Constituting learning communities typically requires small financial investment and generates large impacts on student achievement and retention.

Examples of effective programs.

Programs that bring about high persistence make a concerted effort to address learning, motivation, and professional socialization, frequently early research experiences, active learning techniques, and learning communities (Fig. 1). The programs highlighted here fully address all the elements of the persistence framework in unique ways.

The University of Maryland-Baltimore County Meyerhoff Scholars Program is a stellar example that has increased student performance, achievement, retention, and graduate study in STEM fields. Between 1993 and 2006, of their 508 participating STEM majors, Meyerhoff boasts 86% retention in STEM, 87% of whom pursued graduate or professional school degrees (13). The Meyerhoff philosophy -- "academic and social integration, knowledge and skill development, support and motivation, and monitoring and advising" (13) -- incorporates the three elements of the persistence framework with a simple prescription: it promotes learning through active engagement in and out of the classroom; motivates students through peer mentoring and faculty advising; and encourages students to identify as scientists by offering both social and academic group activities. The Supplemental Materials highlight several other exceptional examples of the persistence framework principles in action, including the peer-led Gateway Science Workshops at Northwestern University (51); the LA-STEM and HHMI Research Scholars Programs at Louisiana State University (52), and the Posse Program (14).

Notably, each successful program actively promotes professional identification, the most recent addition to the body of research that generated the persistence framework (11, 53). The Posse Program, for example, is predicated on building a close cohort of students from the same high school who attend college together and participate in numerous activities that encourage them to identify with their peers and mentors as scholars and professionals. Program designers, funders, and participants would be well served to ensure that investments in other elements of retention programs are reinforced with opportunities for professional identification.

Recommendations and conclusions.

Simultaneously addressing multiple dimensions of the STEM experience is critical to successful retention programs. Sufficient research demonstrates the importance of learning, motivation, and professional identification to suggest a framework for design of effective retention programs that will enable the U.S. to achieve the supply of STEM workers necessary for healthy economic growth over the next decade, programs. Actions that would advance these goals include the following:

1. **First- and second-year students should participate in research.** Universities can replace traditional introductory laboratory courses with research courses for all students and research experiences in faculty labs for an interested subset of students. Federal agencies can assist with short-term funding for the transition to research courses. Private corporations and government labs can contribute by providing research internships to students from colleges without active research programs.
2. **Active learning should be practiced in all introductory STEM courses.** Universities and colleges, professional societies, and funding agencies should provide opportunities and incentives for graduate students, postdoctoral trainees, and faculty learn how to implement active learning techniques effectively (1, 54). To minimize duplication of effort and make the transition to active learning easier for instructors, a searchable database should provide ready access to the vast array of classroom resources that already exist.
3. **Undergraduates should participate in STEM learning communities.** Institutions should create campus locations, including residential communities, for congregation of STEM students. During first-year college orientation, students should learn about existing STEM learning communities and the

> benefits of participating in them. Instructors should provide students with assistance and incentives to form inclusive study groups. Special interest groups, such as science clubs, that demonstrate broad demographic representation should be provided with institutional support for campus events, sponsoring visitors, and travel to professional meetings. Institutions should invest in social networking software that enables students to study together through a web interface.

These efforts can be encouraged by federal and private agencies that fund programs aimed at increasing student retention in STEM. The persistence framework can provide an evidence-based tool for designing and evaluating such programs, while also pointing to areas of education research that is needed to attain sufficient STEM college graduates needed for strong economic development.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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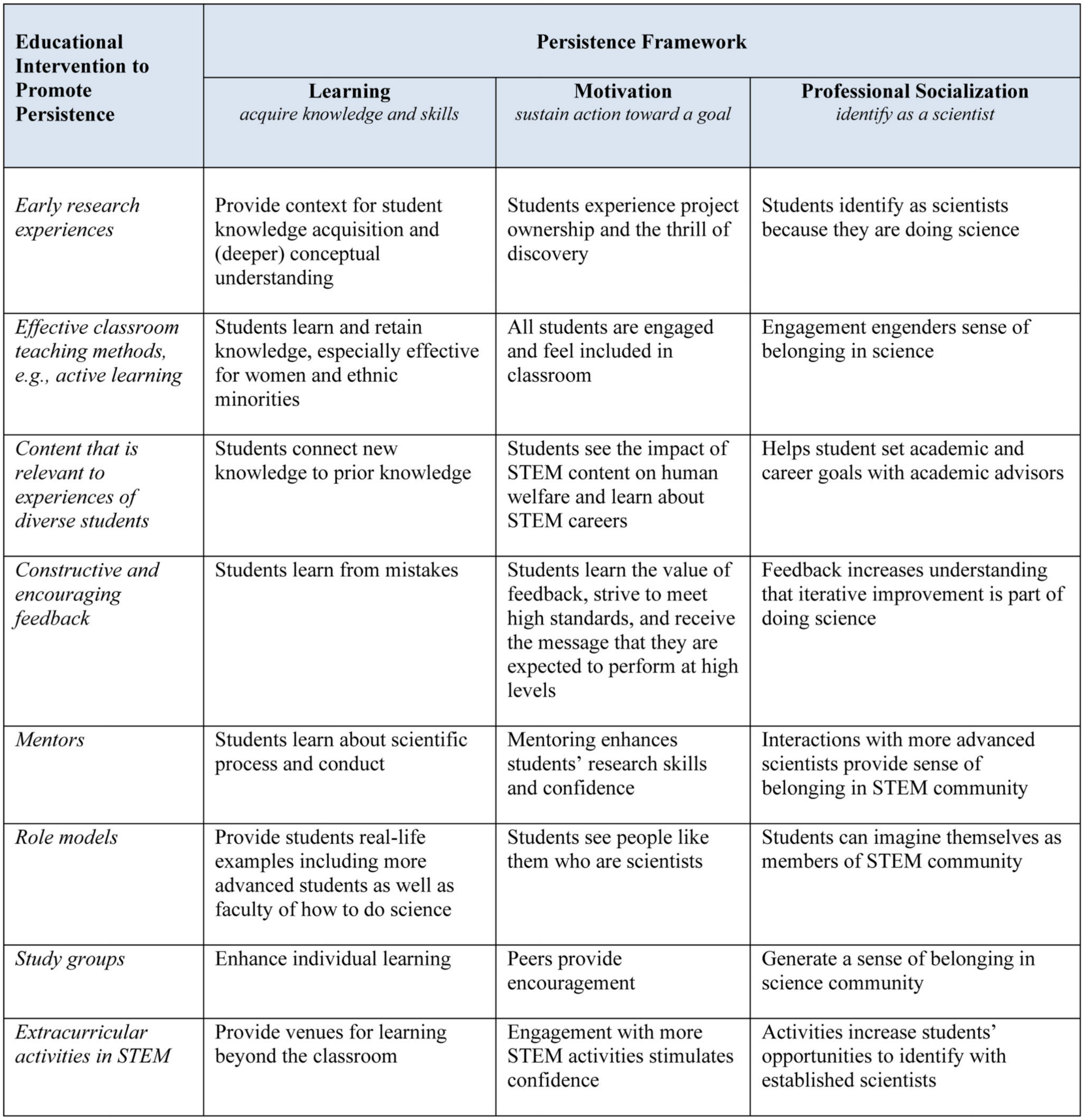

Educational Intervention to Promote Persistence	**Persistence Framework**		
	Learning *acquire knowledge and skills*	**Motivation** *sustain action toward a goal*	**Professional Socialization** *identify as a scientist*
Early research experiences	Provide context for student knowledge acquisition and (deeper) conceptual understanding	Students experience project ownership and the thrill of discovery	Students identify as scientists because they are doing science
Effective classroom teaching methods, e.g., active learning	Students learn and retain knowledge, especially effective for women and ethnic minorities	All students are engaged and feel included in classroom	Engagement engenders sense of belonging in science
Content that is relevant to experiences of diverse students	Students connect new knowledge to prior knowledge	Students see the impact of STEM content on human welfare and learn about STEM careers	Helps student set academic and career goals with academic advisors
Constructive and encouraging feedback	Students learn from mistakes	Students learn the value of feedback, strive to meet high standards, and receive the message that they are expected to perform at high levels	Feedback increases understanding that iterative improvement is part of doing science
Mentors	Students learn about scientific process and conduct	Mentoring enhances students' research skills and confidence	Interactions with more advanced scientists provide sense of belonging in STEM community
Role models	Provide students real-life examples including more advanced students as well as faculty of how to do science	Students see people like them who are scientists	Students can imagine themselves as members of STEM community
Study groups	Enhance individual learning	Peers provide encouragement	Generate a sense of belonging in science community
Extracurricular activities in STEM	Provide venues for learning beyond the classroom	Engagement with more STEM activities stimulates confidence	Activities increase students' opportunities to identify with established scientists

Fig. 1.

The persistence framework. Impact of interventions that promote student persistence and increase retention.