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Hierarchical Mentoring: A Transformative Strategy for Improving Diversity and Retention in Undergraduate STEM Disciplines

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Abstract In the United States, less than half of the students who enter into science, technology, engineering, and mathematics (STEM) undergraduate curricula as freshmen will actually graduate with a STEM degree. There is even greater disparity in the national STEM graduation rates of students from underrepresented groups with approximately three-fourths of minority students leaving STEM disciplines at the undergraduate level. A host of programs have been designed and implemented to model best practices in retaining students in STEM disciplines. The Howard Hughes Medical Institute (HHMI) Professors Program at Louisiana State University, under leadership of HHMI Professor Isiah M. Warner, represents one of these programs and reports on a mentoring model that addresses the key factors that impact STEM student attrition at the undergraduate level. By integrating mentoring and strategic academic interventions into a structured research program, an innovative model has been developed to guide STEM undergraduate majors in adopting the metacognitive strategies that allow them to excel in their programs of study, as they learn to appreciate and understand science more completely. Comparisons of the persistence of participants and nonparticipants in STEM curricular, at the host university and with other national universities and colleges, show the impact of the model's salient features on improving STEM retention through graduation for all students, particularly those from underrepresented groups.

Keywords Underrepresented · Retention · Mentoring · Undergraduate research · STEM · Graduation rate

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Introduction

Global economic changes have increased the demand for science, technology, engineering, and mathematics (STEM) professionals in the United States (US) (Science and engineering indicators 2006). This increasing need has led to greater scrutiny of the matriculation and retention of STEM majors at colleges and universities across the nation. Unfortunately, the undergraduate attrition rate for students who major in the STEM disciplines remains one of the highest in the overall population of undergraduate students in the US (Tinto 1993). Nationally, less than half of the students who enter into STEM undergraduate curricula as freshmen will actually graduate with a STEM degree (Hayes et al. 2009). In part due to these high attrition rates, the international ranking of the US with regard to the production of STEM professionals is low and, as some political leaders and others have noted, has the potential to threaten the nation's economic dominance in the global marketplace (Committee on Prospering in the Global Economy of the 21st Century (US) and Committee on Science Engineering and Public Policy (US) 2007; Galama et al. 2007; Lapointe et al. 1989; McKnight et al. 1987).

The high attrition rate among STEM majors has generated a significant body of research which has led to the development of numerous intervention and prevention programs. While some of these programs have targeted the preparation STEM majors receive prior to enrolling in post-secondary programs, others focus on the experiences of STEM students on college or university campuses. The Howard Hughes Medical Institute (HHMI) Professors Program at Louisiana State University (LSU) has been designed to increase the number of undergraduates, particularly underrepresented students, completing STEM degree programs. The programmatic mission has been to select students with strong secondary education backgrounds who were *underachieving* academically at the undergraduate level and provide them with academic interventions, mentoring, research experiences, and financial support. In this way, the LSU–HHMI Professors Program was designed to facilitate a reversal in a pattern of academic underperformance and to further stimulate student retention. The program incorporates elements from successful programs in the LSU Department of Chemistry (Collins et al. 2001) and the Center for Academic Success (CAS) (Hoffmann and McGuire 2009), as well as lessons learned from similar projects at other universities (Gandara and Maxwell-Jolly 1999; Maton and Hrabowski 2004).

Theoretical Framework

Using an evidence-based approach, an undergraduate STEM education program has been designed to address the key factors leading to student attrition from STEM fields. At the core of this program's design is the belief that mentoring, education, and research are the key components that will result in college and post-college persistence in STEM fields (Fig. 1). These components are clearly identifiable and their theoretical underpinnings provide support for their inclusion in the program design.

Mentoring forms the foundation of the program. Studies show that undergraduate students who are mentored tend to have higher GPAs, higher retention rates, and more units

Fig. 1 Theoretical framework of an undergraduate program designed to increase student retention in undergraduate science, technology, engineering, and mathematics disciplines

completed per semester as compared to their un-mentored colleagues (Campbell and Campbell 1997). Mentoring addresses key facets of student identity and social integration into scholarship and academe as a community (Redmond 1990; Jacobi 1991; Freeman 1999; Good et al. 2000; DuBois et al. 2002) and provides a core support system for students traditionally underrepresented in STEM fields (Good et al. 2000; Gurin et al. 2002; Summers and Hrabowski 2006). With this in mind, the undergraduate program studied in this under study ensures that each undergraduate participant has mentoring relationships with faculty, staff, and their peers. Additionally, we host mentor training workshops for faculty and graduate students who frequently interact with our students (Pfund et al. 2006; McGuire 2007). A key component of this effort is our requirement that the mentee-scholars must mentor others, particularly their peers. In this manner, the key survival skills which are imparted to the mentee-scholars are then reinforced.

Secondly, undergraduate *research* has been shown to be strongly correlated with enhancement of the undergraduate education experience (Lopatto 2004; E. Seymour et al. 2004; Bauer and Bennett 2003; Chopin 2002; Sabatini 1997) particularly reduced attrition rates (Nagda et al. 1998) and increased rates of graduate education (Hathaway et al. 2002) for all students, especially underrepresented students. Furthermore, undergraduate research has been shown to be associated with the attainment of research skills (Kardash 2000; Lopatto 2004), increased persistence to the undergraduate degree (Nagda et al. 1998), and influencing the selection of a STEM career (Zydney et al. 2002). The undergraduate program under study has embraced these findings and makes certain that all participants are engaged in undergraduate research as early as possible. We have developed and sponsored student-focused workshops on securing research experiences and have also developed partnerships with faculty interested in providing research opportunities to our students.

The final component of our three-pronged approach to undergraduate persistence in STEM is *education*. Broadly speaking, education addresses issues such as learning styles (Jones et al. 2003; Burke and Dunn 2002), cognitive and metacognitive learning strategies (DeHaan 2005; Novak 2002), group study (Crouch and Mazur 2001; Springer et al. 1999), navigating competitive and collaborative academic settings (Bergin and Cooks 2000; Elaine Seymour and Hewitt 1997b), successful completion of gateway courses (Barlow and Villarejo 2004; Moreno and Muller 1999; Fullilove and Treisman 1990), recognizing (and when necessary overcoming) racial and academic identities and their roles in student success (Fries-Britt 1998; Steele 1997; Tinto 1987), social integration (McKinney et al. 1998), navigating the research enterprise, community service, effective presentations, service-learning, GRE preparation, and preparing competitive graduate applications. Largely, the education component is implemented through a series undergraduate success courses. Through these flexible and adaptive professional and academic development courses, program staff, affiliated faculty, and several additional campus entities (e.g. the Center for Academic Success, the Wellness Education division of the Student Health Center, and Career Services) offer the LSU–HHMI program participants workshops on the aforementioned topics. Additionally, students learn about research opportunities at LSU and beyond, and they engage in peer mentoring and support activities.

Through this trifecta of mentoring, research, and education, participants in the LSU–HHMI Professors Program are engaged in very structured activities which support their academic and professional development. Herein, most students learn to successfully navigate their academic paths and become leaders who teach others what they have learned.

Model Design

The LSU–HHMI Professors Program incorporates and implements the mentoring, research and education components through its Mentoring Model (Fig. 2). This model has been strategically designed to address the key factors that have been shown to significantly impact STEM student retention: (a) academic performance in undergraduate coursework, (b) self-image, (c) pre-college background, (d) academic advising, (e) financial support, and (f) social integration in the STEM culture (Braxton et al. 2004; Tinto 1993; Metzner 1989; Seidman 2005; Elaine Seymour and Hewitt 1997a). The principal partners in designing and testing this model have been the LSU Office of Strategic Initiatives, led by Prof. Warner, and the LSU Center for Academic Success, formerly led by Prof. Saundra McGuire. At the core of this model is the belief that any student who is motivated to change maladaptive behaviors, willing to embrace new experiences, and has access to necessary support structures can become successful. Having garnered years of anecdotal evidence of the consistent and dramatic improvement in the performance of STEM students after receiving mentoring and academic interventions, Professors Warner and McGuire collaborated to develop this mentoring model.

Using the mentoring ladder, the program provides comprehensive support services to students. These include (1) collaboration with the CAS to provide a thorough assessment of learning styles, a repertoire of effective metacognitive learning strategies, and effective study strategies; (2) challenging research opportunities; (3)

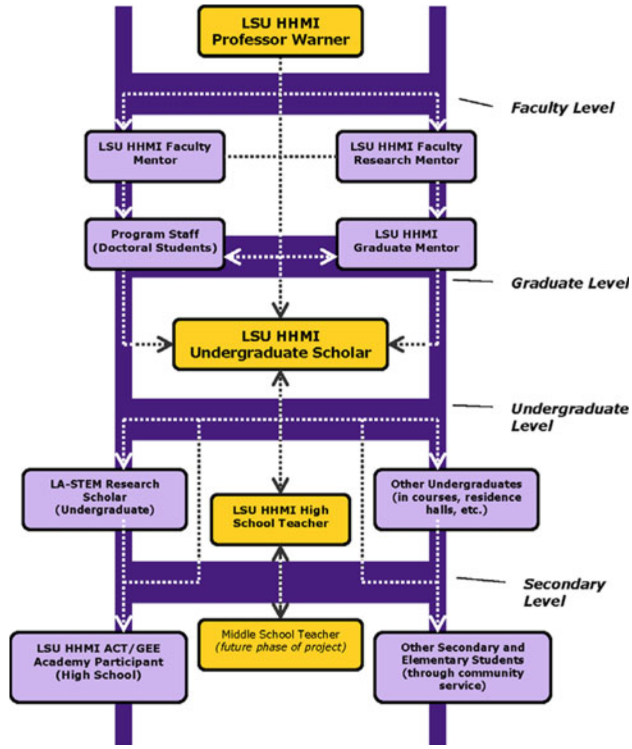

Fig. 2 LSU–HHMI Professor Program Mentor Model

mentor and mentee interactions; and (4) advising and support structures that help students navigate the path from a mindset of failure and helplessness to one of empowerment and success. These programmatic components, integrated into the mentoring model, facilitate participants' evolution from those who are mentored to becoming mentors; from those who are tutored to those who tutor; from those who receive advising to those who serve as advisors and role models. We have found that this strategic progression towards reciprocal responsibility on the part of each student reinforces the success strategies taught to participants. Herein, LSU–HHMI Professors Program undergraduate participants (i.e. LSU–HHMI Scholars) develop a strong sense of community and are taught the fundamental principles of mentoring, metacognition, and research through classes and interactions with their peers, graduate students, high school students, program staff, CAS learning strategists, and faculty at the college, high school, and elementary school levels.

LSU undergraduate students are invited to apply to become LSU–HHMI Scholars based on two factors: (1) academic underperformance during their freshman year as STEM majors and (2) their potential in the STEM areas as suggested by their pre-college background and performance. Once selected, LSU–HHMI Scholars are given mentoring and research experiences that help their integration into the STEM community of learners. After being introduced to basic learning principles by CAS, these students develop the metacognitive strategies that propel them upward on Bloom's hierarchy of learning levels (Fig. 3) and this higher level learning allows students to appreciate and understand science more completely (Anderson et al. 2001).

Participant Criteria

Since inception in academic year (AY) 2002–2003, nearly one hundred LSU undergraduates have entered the LSU–HHMI Professors Program Hierarchical Mentoring Model. While a core criterion of participation is academic *underperformance* in the first year of STEM undergraduate study at LSU, an additional criterion is a demonstrated potential for success in STEM fields, as evidenced through the participants' high school academic background and performance. Program participants, called LSU–HHMI Scholars, were selected through a rigorous application process which included written essays, interviews with faculty and staff mentors, and letters of recommendation. Upon entry into the mentoring model, these Scholars typically have a grade point average between 2.5 and 3.0, must have significant interest in long-term careers in STEM, and must fully commit to participating in all aspects of the mentoring model. At the onset of the LSU–HHMI Professors Program, a limited number of students entered the program with GPAs above 3.0; these LSU–HHMI Scholars were selected because of their potential as role models during the early development of this program. In later years, a sister program, LA-STEM Scholars served in this capacity.

While most LSU–HHMI Scholars entered the mentoring model as rising sophomores, a small number have entered as rising juniors. For the purposes of this study, all LSU–HHMI Scholars have been combined into one large cohort and have collectively been evaluated to gauge the success of the LSU–HHMI mentoring model. A key point of interest for this group is its demographics by ethnicity (Fig. 4). Another key point of interest for this group has been the retention and graduation rates for students in STEM undergraduate curricula at LSU and beyond.

Beyond the LSU–HHMI Scholars, two other groups who have not participated in the LSU–HHMI Mentoring Model have been included in this study for the sake of comparison. The non-participant LSU STEM undergraduate population forms a group; retention data on these LSU STEM undergraduates have been collected by the LSU Office of Budget and Planning's Institutional Research Team. STEM undergraduates in more than 200 US colleges and universities form the final group, and retention data of these nation-wide STEM undergraduates have been collected by the Consortium for Student Retention Data Exchange (CSRDE) at the University of Oklahoma (Hayes et al. 2009).

Mentoring: A Transformative Strategy for Improving Retention and Diversity

We have found that the strategies employed through the LSU–HHMI Mentoring Model collectively lead toward

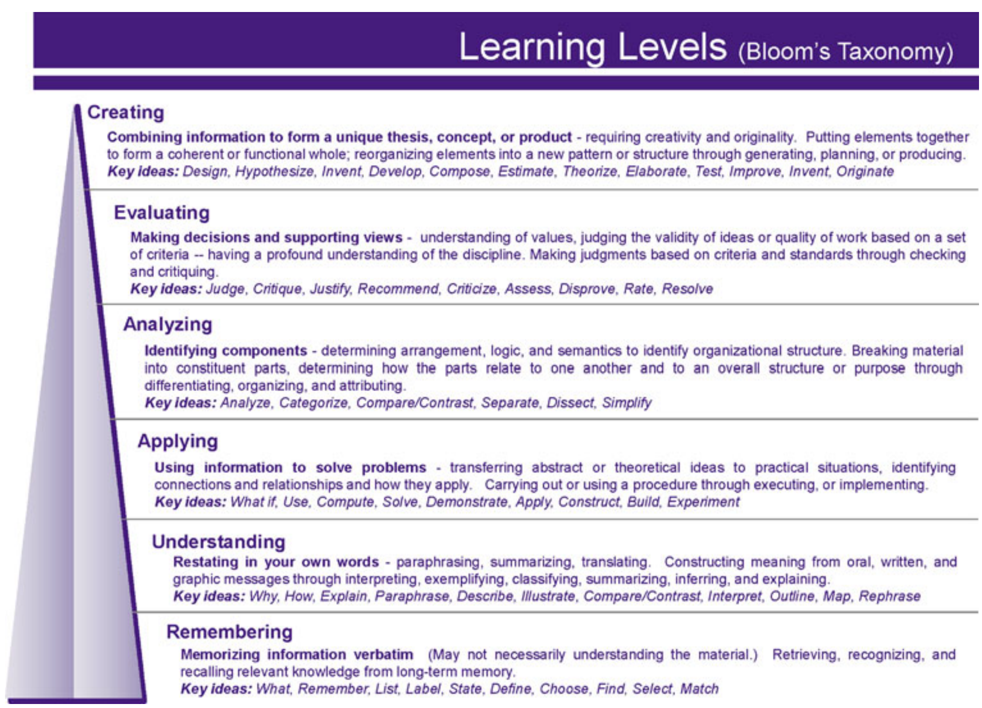

Fig. 3 Bloom's Taxonomy, outlining higher-order cognitive skill sets

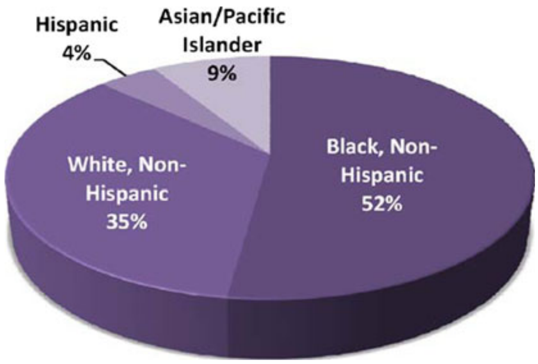

Fig. 4 Demographics of the LSU-HHMI Scholars, by ethnicity

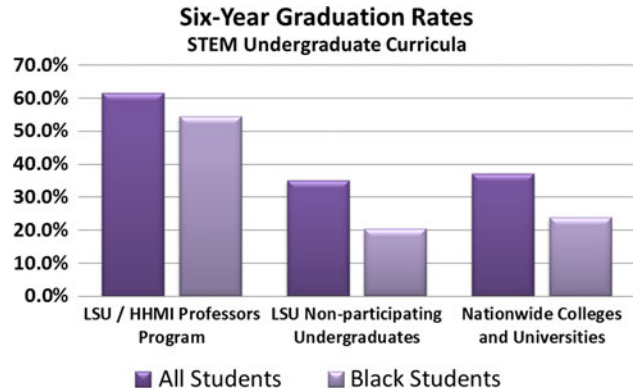

Fig. 6 Six-year graduation rates for the LSU-HHMI Professors Program Scholars, LSU incoming freshmen in STEM curricular for AY 2002–2003, and national consortium incoming freshmen in STEM curricular as reported by the Center for Institutional Data Exchange and Analysis at the University of Oklahoma

greater retention and STEM graduation rates for all participants, but particularly those from underrepresented groups. Historically, the STEM undergraduate retention rates at LSU have been low. For students entering LSU from fall 1998 through fall 2003, the six-year graduation rate of students who entered STEM curricula as freshmen and continued through to BS degree attainment (in a STEM field) ranged from 32 to 35% per year and the graduation rates for African American students, the largest minority group at LSU, ranged from 19.2 to 23.5% (Fig. 5).

The LSU–HHMI Professors Program, initiated in Academic Year (AY) 2002–2003, has been able to reverse this trend. Comparing the graduation rates of LSU–HHMI Scholars to (1) LSU STEM undergraduates, and (2) nationwide STEM undergraduates (Hayes et al. 2009), provides strong evidence of the success of the mentoring model in helping to retain students in STEM fields (Fig. 6). For this comparison study, we have used the CSRDE method wherein two cohorts are identified, i.e. students from all ethnicities were included in the "All" category and only African American students were included in "Minority" group.

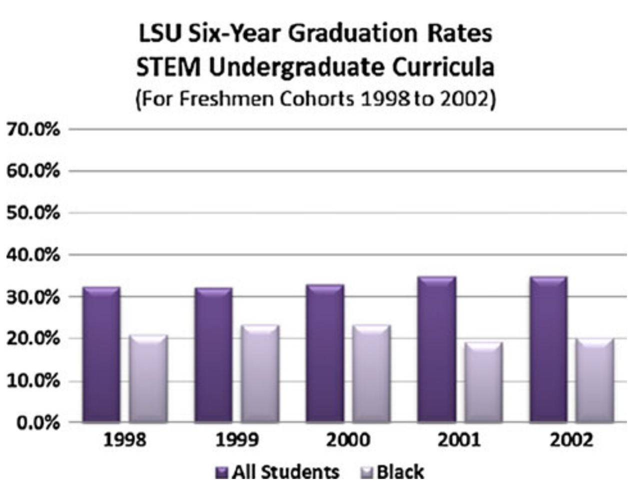

Fig. 5 Six-year graduation rates for all incoming freshmen entering into LSU STEM undergraduate curricula, 1998 through 2002

Examination of retention data shows that LSU–HHMI Scholars are significantly more likely to complete a STEM undergraduate degree than is true of other LSU non-participating students. With six-year STEM graduation rates of 62 and 55% respectively for all and minority students, LSU–HHMI Scholars were significantly more successful in completing STEM BS Degrees than non-participants at LSU. Moreover these students are low-performing students who overcome academic challenges and are retained in the STEM disciplines. These outcomes are also better than the national average as polled and reported by the CSRDE (Hayes et al. 2009). Notably, our African American Scholars are completing STEM degrees at approximately the same rate as the all other students. This almost parity in graduation rates for minority students represents the greater success of the LSU–HHMI Professors Program Mentoring Model in addressing student persistence in STEM fields and shows that the integration of mentoring and academic interventions into a structure undergraduate research program has the potential to dramatically impact student persistence in STEM undergraduate curricula.

To further probe the saliency of the LSU–HHMI Professors Program Hierarchical Mentoring Model on student retention, we have analyzed the rates of retention and graduation based on student entrance into the model. Although the model was designed for students in the early portion of their undergraduate education, i.e. freshmen and sophomores, we have also admitted students at all levels of education. Consequently, it is important to assess the impacts of the model on students who entered at the early and latter stages of their undergraduate studies.

Of the program participants, the majority entered the model at either the freshmen or sophomore levels (Fig. 7). Participants, entering at the freshmen level, joined the model after their first semester at LSU, and participants

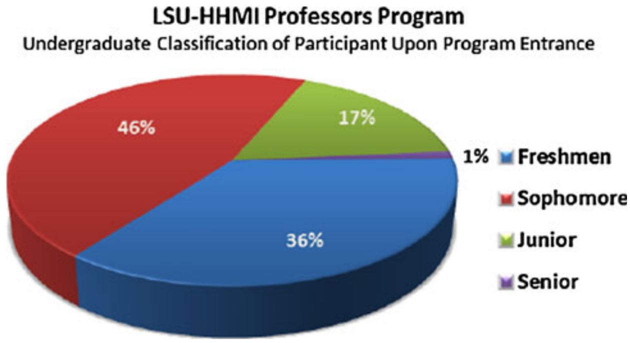

Fig. 7 Demographics of undergraduate participants, upon entry into the LSU-HHMI Professors Program Hierarchical Mentoring Model

entering at the sophomore level, entered after their second semester.

Our study shows that the model's impact on student retention at either of these early stages yields comparable results, whether evaluating students' retention through graduation in a STEM discipline or a non-STEM discipline. The overall graduation rates were 73.9 and 76.7% for students entering the LSU-HHMI Hierarchical Mentoring Model at the freshmen and sophomore levels, respectively. The overall graduation rate for students at LSU who enter in a STEM degree program and exit the university with some degree whether STEM or non-STEM is 55.9%. Consequently, the graduation rates for LSU-HHMI Professors Program participants represent an average 20 point increase over the graduation rates for the comparable group of students (Fig. 8). Notably the students who entered at the sophomore level were more likely to complete a STEM degree than those who entered at the freshmen level. However those students who were not retained in STEM disciplines were more likely than non-participants to graduate with a baccalaureate degree. Anecdotal evidence has been gathered from this group and many have attested that the learning strategies, attained through program participation, prepared them for success in all degree programs.

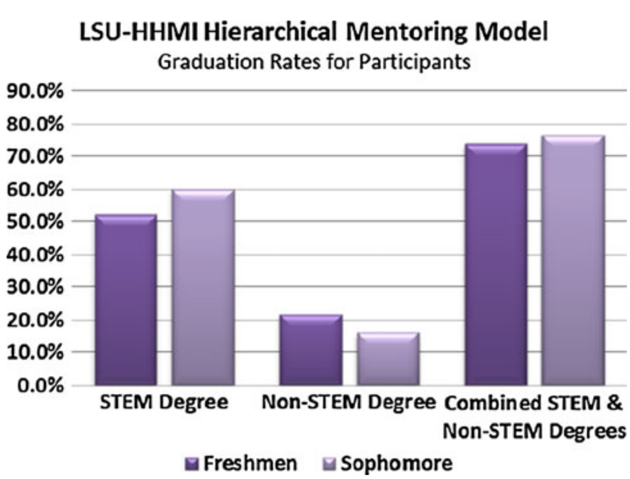

Fig. 8 Six-year graduation rates for undergraduates entering into the LSU-HHMI Hierarchical Mentoring Model at either the freshmen or sophomore levels

Discussion and Summary

The LSU–HHMI Professors Program retention success, although dramatic, garners attention because of the specific requirement that the selected participants had to be academic underperformers. This selection criterion strengthens the findings reported here since the participants were not selected for superior academic performance as compared to other STEM undergraduates as one might assume. The LSU–HHMI Scholars were selected *because* of their academic *underperformance*. The goal of this program has been to help these students to learn to think more deeply about science by providing research experiences and targeted academic interventions. The success that we have had with increasing the retention rates of students in the HHMI Professors Program, particularly as compared to the general population at LSU, has revolved around several factors which we have identified and described below.

1. *Realization*, after attending a learning strategies presentation or meeting at the CAS, that what they are currently doing is not working; this may be poor time management (particularly wrong or inconsistent choices), learning strategies that they employ which most likely are low on Bloom's Taxonomy and learned habits from high school that perpetuate academic decline. Inattention to courses in which they have little interest, not understanding or committing to the truth that mastery takes 'work,' etc.
2. An *honest commitment* to systematically identify exactly what is not working; this comes as a result of academic advisement during mentoring meetings and following up on all "intervention" assignments, honestly communicating with the program staff about their current academic status and progress, learning from interactions and insights from faculty research mentors, staff, other professional/academic support mentors, and program peers, taking their individual development plan seriously.
3. *Changes in mindset* about their ability to learn the "hard" subject matter, particularly for under-represented students in comparison to majority students; stepping outside of isolation (perceived or real) as a 'minority' student and not allowing that to hinder them academically.
4. *Committing to work through* the plan of action.
5. *Following through on their commitment* which prevents them from relapsing into old academically destructive habits and ways of thinking.

6. *Continuous improvement* which develops sustained personal pride and *great satisfaction in the outcome* which propels them to maintain what they have obtained.

We have found that mentoring, undergraduate research, academic interventions, and career exploration opportunities play critical roles in student embracement of the above mentioned factors. The LSU–HHMI Scholars are infused into the mentoring ladder which aids in introspection and initiates the mental processes required to overcome the negative cognitive effects of academic failure (Bosson et al. 2004; Carr and Steele 2009; O'Brien and Crandall 2003; Steele and Aronson 1995; Steele et al. 2002). Overcoming negative cognitive processes aids in students' changed mindsets and leads to gains in the students' educational experiences (Dweck 2006). The learned helplessness and overall decreased esteem associated with academic decline is also resolved through individualized academic advising designed to direct a student's metacognitive journey into academic success. In addition, participants are required to conduct undergraduate research and present at conferences. This socialization of students into the scientific community facilitates personal growth for the students and reinforces their self-identity as STEM researchers (Berger and Milem 1999; Gurin et al. 2002; Hausmann et al. 2007; Locks et al. 2008). Employing such techniques are tangible ways LSU HHMI Professors Program contribute to students' transition from academic underperformance and their resulting retention through graduation. We note that the participants in the study are paid a nominal stipend for participation in the program and thus may be more motivated to change and adapt their behavior than is true of the comparison group. However, we should also note that improvement in academic performance was not a criterion for remaining in the LSU HHMI Professors Program. Thus, we believe the higher levels of STEM degree completion is based on those students who were selected to participate in this program and chose to embrace the concepts outlined in the LSU HHMI Mentoring Model.

The reversal of academic decline was a key factor that contributed to students' persistence in STEM majors. The comprehensive mentoring approach provided through the LSU HHMI Professors Program was vital to stemming attrition from STEM undergraduate curricula, particularly with underperforming students. The results for two cohorts suggest that LSU–HHMI Scholars experience greater retention through graduation than for non-participating STEM undergraduates at LSU. Surveys of participants and interviews with project staff linked this outcome to attitudinal and behavioral changes brought on by the students themselves and the various components of the program. Particularly important, according to participants, was the role of the mentoring component of the program in concert with research opportunities, peer interactions, and academic support services. The mentoring component was comprehensive and multidimensional including faculty research mentors, research group mentors (including graduate students and postdoctoral researchers), CAS staff, and LSU HHMI Professors Program staff advisors and peer mentors.

In summary, our findings suggest that increased metacognitive sophistication and mentoring play critical roles in helping these students to successfully complete their undergraduate studies and prepare for graduate study and/or entrance into the STEM workforce. Through well-designed mentoring programs, students develop constructive strategies for enhancing their higher-order thinking skills which help them to appreciate and understand science more completely and often result in improved academic/coursework performance. Mentoring helps students to realize and envision their self-identity as STEM scholars with the potential to offer meaningful contributions to their disciplines. The HHMI Professors Program at LSU actualizes the traditional apprenticeship model, which through the ages has demonstrated its enduring practicality and is even now fostering the next generation of STEM practitioners as they gain the skills and confidence to galvanize the next age of scientific and technological advances.

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