CUR Quarterly

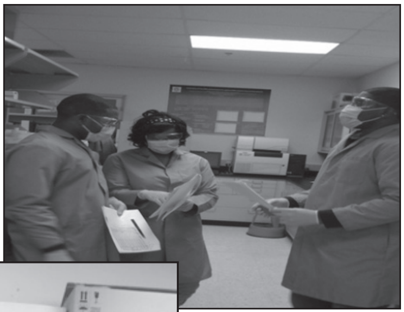
CUR Focus

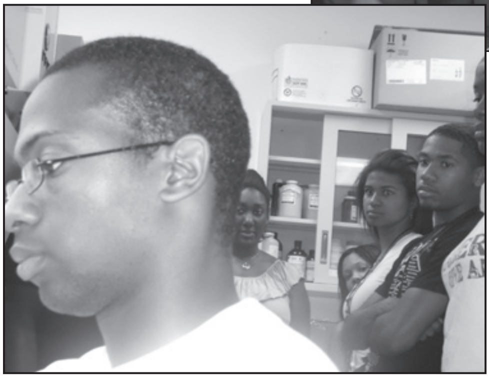
Kanyand Matand,
Ning Wu, Lisa L Rollins
Langston University

Developing a Better Way to Improve the Research Skills of Underrepresented Students

Background

Participants at a statewide conference on undergraduate research in Oklahoma in March 2010 agreed that an undergraduate research experience is a most significant component of the total package for effective education of undergraduate students. Indeed, undergraduates are increasingly perceived and recognized as producers of knowledge (Griffiths 2004; Gibbon et al. 1994). Consequently, it is increasingly accepted that undergraduates are expected to develop research skills and experiences *prior* to entering graduate school or a profession. Such expectations are grounded in studies showing that predominantly undergraduate institutions are a significant, if not the most important, source of scientific talent in the U.S. (Tobochnik 2001). The Council on Undergraduate Research (CUR), which has long crusaded for widespread access for undergraduates to research opportunities at undergraduate institutions, deserves credit for encouraging research experiences.





Right: Showing students discussing molecular genetics protocols in the middle of an experiment
Left: A senior student introducing freshmen to his cell biology experiment

Yet underrepresented students still have fewer opportunities, and continuous efforts toward developing the most efficient methods for providing such experiences to minority students are essential in realizing the goal stated by Jenkins and Healey (2007) that "undergraduate research should be accessible to all students."

Langston University is a predominantly undergraduate member of the group of Historically Black Colleges and Universities. It is located in Oklahoma and has a mission of educating future leaders and role models for underrepresented communities. To achieve this goal, the *Langston University Center for Biotechnology Research and Education* took on the task of developing a more effective approach for providing competitive undergraduate research experiences to underrepresented students, regardless of their GPAs.

Special Challenges with Underrepresented Students

Most of our students come from low-income families, so one of their greatest challenges is to secure scholarships or loans or else work many hours daily for minimum wages to pay for even a portion of their tuition and other costs. Having to work means fewer hours of studying, and yet many of minority students attend high schools without rigorous courses in science, mathematics, technology, or English. This has profound implications at the college level.

For example, while many of our incoming students enter with high school GPAs of more than 3.0, those tend to decline sharply for the first year, or so, of college work. Many students may eventually work back to a 3.0 GPA or better, but one typical eligibility criterion for participation in internships or other forms of undergraduate research is that a student must have consistently earned at least a 3.0 GPA. This criterion also applies to graduate school admissions or employers' selection processes. Students' GPAs, thus, may not indicate a lack of intellectual potential, but rather merely reflect their prior inadequate educational background-deficiency that might be remedied with adequate supplemental training and/or mentorship programs. We believe that students, who thrive academically in high schools with less rigorous study programs, should also possess the intellectual potential to be competitive in

Table 1: Student academic and training-related information

Student (names withheld)		Academic information at the start of the program				Student training-related status			
		Student classification		GPA*		Current status		Training status	
NM	**CM**	**NM**	**CM**	**NM**	**CM**	**NM**	**CM**	**NM**	**CM**
1	11	Jr.	Jr.	3.0-3.7	4.0	Job	Job	Completed	Completed
2	12	Sr.	Jr.	3.0-3.7	4.0	GS	GS	Completed	Completed
3	13	Jr.	Jr.	2.6	4.0	BS	GS	Completed	Completed
4	14	So.	Jr.	3.0-3.7	4.0	BS	Job	In progress	Completed
5	15	Jr.	So.	3.0-3.7	3.5-3.9	GS	NJ	Completed	Completed
6	16	Sr.	Sr.	2.7	3.5-3.9	GS	GS	Completed	Completed
7	17	So.	Jr.	3.0-3.7	3.5-3.9	BS	Job	Dropped out	Dropped out
8	18	So.	Jr.	3.0-3.7	3.5-3.9	BS	Job	Completed	Completed
9	19	Sr.	Jr.	2.7	3.5-3.9	BS	GS	Completed	Completed
10	20	Sr.	Jr.	3.0-3.7	3.5-3.9	BS	GS	Completed	Completed

well-designed programs of research experiences that take into account their earlier educational challenges.

Experimental Approach

To see if we could improve students' preparation for and performance of undergraduate research, 20 students were randomly selected from among eligible students to participate in a study (Table 1). Ten students selected as a control group were trained to conduct research using our conventional method, described below. These students were selected primarily based on their having high GPAs, 3.5 to 4.0, which would normally help them be considered for research or graduate school opportunities.

The other 10 students were trained using a new method premised on the fact that many underrepresented students attended high schools with less rigorous exposure to STEM fields (Babco 2003) and therefore needed a robust supplemental training method that could work for students with lower GPAs. Unlike the control group, the selection GPAs of this test group ranged broadly, from 2.5 to 4.0. All participating students were science majors.

NM: New training method; *CM*: Conventional training method; *GS*: the student has entered graduate school; *BS*: the student is still pursuing a BS degree; *NJ*: the student is unemployed in his/her area of expertise after obtaining the BS degree; *Job*: the student got a job in STEM field after BS degree. * Difference between the two groups is statistically significant at 5% probability, using T-test.

Conventional training for undergraduate research - The control group of undergraduates was exposed to technical laboratory skills through repeatedly performing various experimental protocols, for instance, for in vitro cell manipulations and gene isolation and cloning, etc., that the students would need to execute to undertake research that we had planned for them (which would be done under the supervision of the laboratory technician and/or mentor). When students felt comfortable applying the protocols, they were generally assigned limited, specific research tasks that would enable them to apply the protocols successfully.

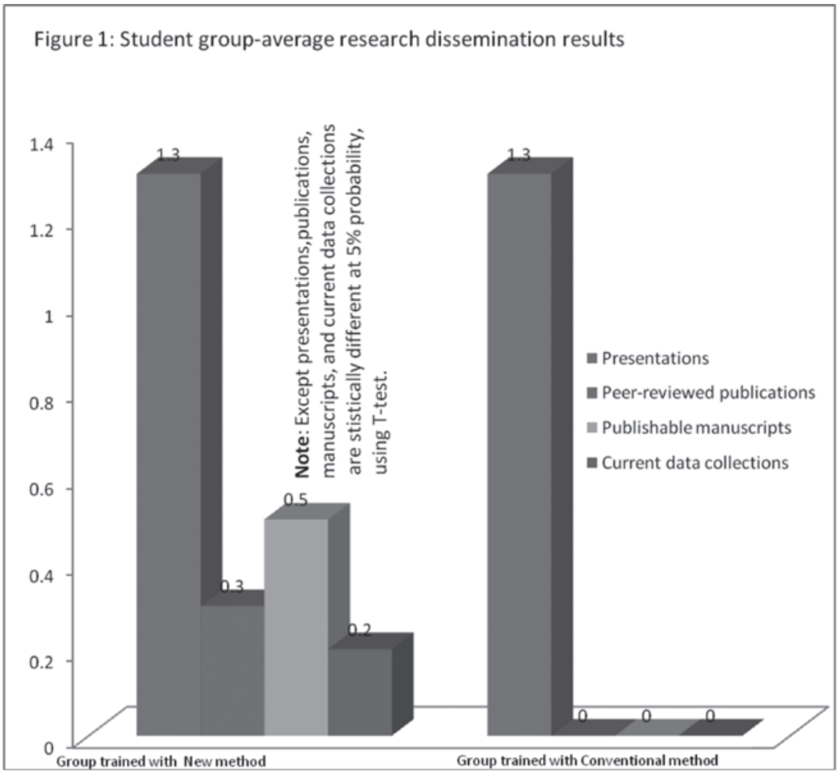


Figure 1: Student group-average research dissemination results
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1.3
0.3
0.5
0.2
1.3
0
0
0
Note: Except presentations,publications, manuscripts, and current data collections are stistically different at 5% probability, using T-test.
Presentations
Peer-reviewed publications
Publishable manuscripts
Current data collections
Group trained with New method
Group trained with Conventional method

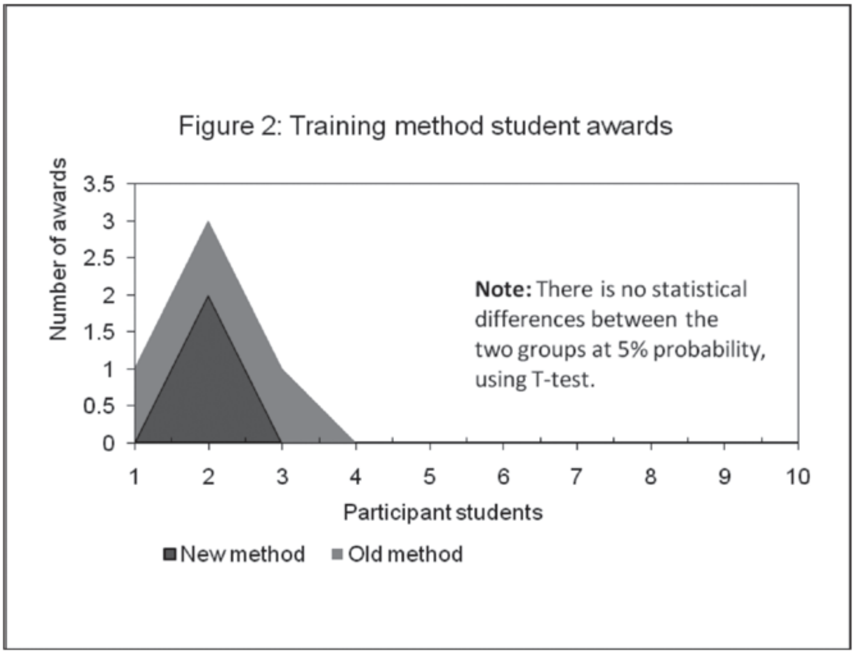


Figure 2: Training method student awards
Number of awards
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
9
10
Participant students
Note: There is no statistical differences between the two groups at 5% probability, using T-test.
New method
Old method

Although they were generally introduced to comprehensive experimental protocols for teaching and learning purposes, undergraduates were assigned a limited role in applying them. For instance, they were taught how to isolate genes, but their work generally was limited to the first step of total RNA isolation for at least three to six months before they were trusted to move on to mRNA purification and other steps.

Although a similar training approach is used with graduate students, the latters' training was generally more intense and comprehensive. Students moved on to more sophisticated tasks more quickly, because graduate students are believed to be more reliable and responsible. Further, they had taken more science courses that facilitated their understanding of what they were doing. Graduate students, unlike undergraduates, realize that they must be proficient in research, which provides an added incentive for them to succeed within a limited time period.

Innovative training for undergraduate research - The new approach consists of six steps: (1) shadowing, (2) theoretical laboratory seminars, (3) technical skills laboratory seminars, (4) student research ownership of others' peer-reviewed studies (students present and defend experimental plans and results of earlier published research), (5) cohort-student re-discovery research (*students replicate earlier published research*), and (6) individual student discovery.

During "shadowing", students toured local academic and research sites that specialized in biotechnology, allowing them to see scientists in action and also enhancing their knowledge of career opportunities in biotechnology. During the three hours of shadowing, students were encouraged to ask questions about what the scientists were doing, what their academic backgrounds were, and what skills they were using to conduct the research. To help enhance their writing skills, students were required to write a report about the shadowing experience.

After shadowing, students were required to attend five hours of laboratory seminars on theoretical biotechnology topics. The sessions were subject-focused and designed to provide targeted background concepts and knowledge to aid students' introduction and transition into the new field. Students were first instructed about tissue culturing and then about topics in molecular biology. On tissue culture, for instance, students were instructed on recognizing, selecting, and manipulating the right cells and tissues suitable for responding to different chemicals to form new plants in the glass. On molecular biology, students were instructed about basic nucleic acid structures, types, functions and how they apply in modern technologies that involve genomic manipulations for crop and animal improvements and human medicine and the like. This was critical considering that none of the participants had taken a biotechnology class or been exposed to any related subject knowledge.

In the third step—five hours of seminars on technical laboratory skills for biotechnology research—students were instructed in specific technical knowledge and protocols with immediate application to their upcoming research projects. This step focused on dissecting actual procedures. For instance, students were instructed on different approaches to accessing genomic or cDNA, cloning and screening for recombinant DNA molecules of interest, and analyzing DNA using genetic analyzers, bioinformatics programs, or microarray printers and scanners. Mentors focused particularly on why specific chemical components or steps are included in individual experimental protocols and the benefits and limitations of those particular protocols.

In the fourth step, students studied examples of peer-reviewed research and were asked to explain why, for example, the investigator used a particular protocol rather than others that the students had discussed earlier in their training, or why a particular technique was used for the genetic analysis. The goal was to provide students with the skills to critically analyze, redesign, and defend an experimental plan, as the actual author would have done before carrying out the study. Students were assisted in discussing the published results as they related to applied protocols.

To enhance students' skills in critical thinking, research, communication, and learning, they were encouraged to submit written and oral reports on the published research just as the original author would do and also were encouraged to report on at least three additional published studies of their own choosing. Mentors assist-

A senior student prepares for collecting daylily flower tissues for in vitro cellular manipulations

ed students in choosing published studies related to the students' upcoming research projects.

In the fifth step, pairs of students applied research that had been completed and reported on to a new laboratory experiment. This step was designed for students to complete within a month; however mentors could allow slower-paced students a reasonable extension of the time period. In addition to learning teamwork skills and critical thinking, this step trained students to recognize and formulate specific research questions. They were also exposed to different research methods of identifying, gathering, evaluating, and synthesizing evidence and information.

Step six, in which students conducted their own research, was designed to be completed within two months. It emphasized encouraging students to operate as the sole or lead scientist on their respective projects and to frame a topic related to the biotechnology program's ongoing research. They were to outline their methodology with emphasis on *what, why,* and *how*. Sample topics of the individual research projects included "shoot induction in the daylily flower" and "screening for organ-specific mRNAs in peanuts."

This step encouraged students to develop their own individual research questions and to initiate investigations, the outcomes of which were unknown. It also encouraged students to acquire additional communication and broader investigative skills, including conducting literature reviews, coding data, and gaining overall laboratory bench skills.

Note: Overall, this study was deliberately designed for more intense learning over one semester period. However, because most students trained earlier with the conventional method took two years to complete the program, due primarily to student differential research schedule that depended upon course load and repeated failed initial experiments, the same length period was also expected for students trained with the new method.

Outcomes

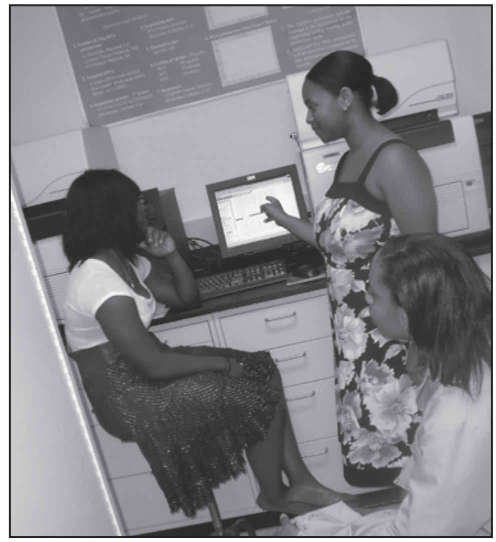
Our experiment with the two groups of students was conducted using Completely Randomized Block Design, and all students were trained within the same laboratory environment. Observations were made daily, and data were analyzed using the T-test. The overall aim was to evaluate the immediate impact of the new training method for the conduct of undergraduate research for underrepresented students in biotechnology at Langston. The bottom line: Eighty percent of trainees, under the new method, have co-authored at least one professional peer-reviewed research manuscript. All peer-reviewed manuscripts and related faculty publications during the last two years (2009-2010) were co-authored by the students and enriched with their incremental inputs. It provided them with the opportunity to experience the responsibility scientists take for their research results. It also taught them skills involving interpreting results and mining subject-specific information in order to make informed arguments on why their results are what they are, or why they agree or disagree with others' research.

The publication rate observed was considerable, especially considering that these undergraduates are from groups typically underrepresented in the sciences (Babco 2003). This underscores the gain and personal transformation in students' learning (Walkington 2008). It is also unprecedented, because over several years of providing research experiences to students using the conventional method, none of the trainees ever generated data significant enough for inclusion in peer-reviewed publications. This in no way diminishes the invaluable contributions and successes of the biotechnology program using the conventional method in providing student learning, hands-on laboratory skills, and overall research experiences. Rather, the most significant meaning of the results is that the new approach is statistically more effective than the conventional one using T-tests (Figures 1, 2, 3, and 4), *regardless of the trainees' GPAs*.

In addition to the development of peer-reviewed publications with the new approach, data showed that both methods resulted in significant participation of students in conference presentations (Figure 1). Accordingly, 80 percent and 90 percent of trainees, who were provided with research experiences through the conventional and new methods, respectively, presented their results at scientific meetings. However, this meeting presentations percentage difference between trainees under each method was not statistically significant. The sole student trained with the new method, who failed to generate data for a conference presentation, dropped out of the program and did not complete training.

In total, five students received national and/or local awards at the meetings for the quality of both oral or poster presentations and innovative research. Three conventionally trained students and two students trained with the new methods received awards (Figure 2). However, the difference *in the numbers of students receiving awards under each approach* was not also statistically different. Except for one student, all awardees had received research and presentation experiences prior to joining the biotechnology program (Figure 3). This might have provided them with an edge over novice students on what to expect and how to handle the pressure during competitive presentations. If so, this underscores the broader benefits of research experience.

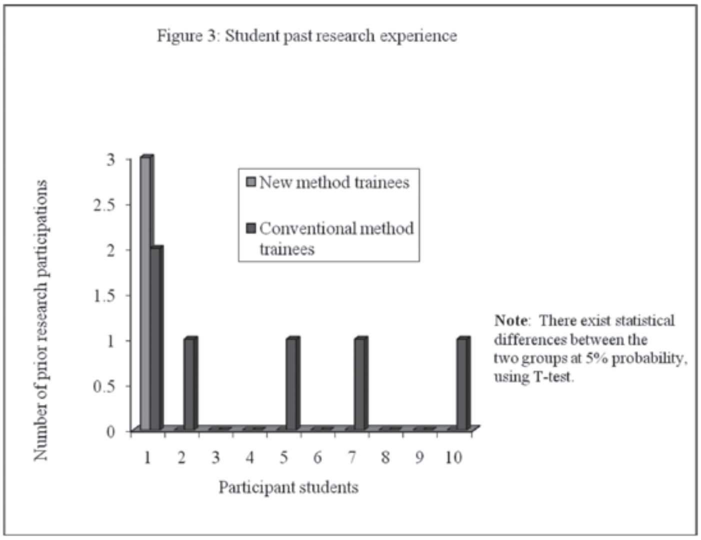
Most surprisingly, the three students with college GPAs consistently below 3.0 prior to joining the program were among the best performers in the laboratory and among the fastest in generating publishable data (Figure 1). One of them, the top-performing student, was recently (September 27, 2010) profiled in the daily news outlet of Historically Black Colleges and Universities, the *HBCU Digest*, (www.hbcudigest.com), and is portrayed among his peers as a local role model. Two other participants whose biotechnology research was also profiled in their

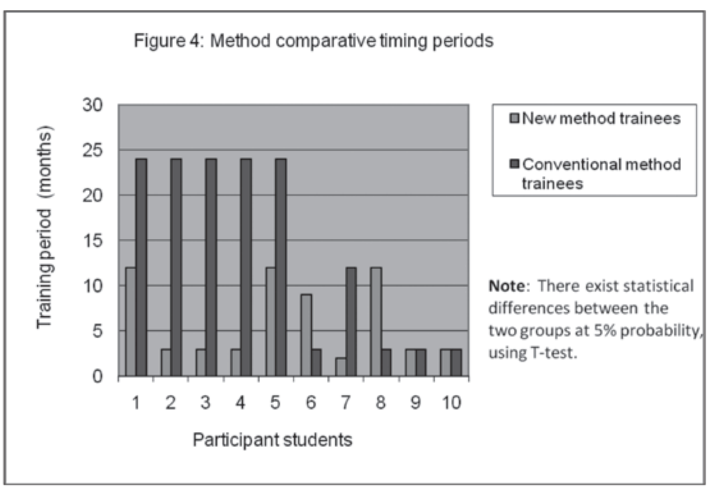


A senior student introducing freshmen to her bioinformatics research project.

hometown newspaper (*Muskogee Phoenix*, September 10, 2010), were flooded with complimentary phone calls from local residents, who hailed them as heroes and role models in the community. One of them had a GPA under 3.0. A local pastor of one of them even touted her accomplishment during a Sunday church sermon. The students gained considerable standing in the community as a result of their innovative biotechnology research projects and research experience successes, which underscores the urgency of developing adequate instructional methods for leveling educational disparities among income groups.

Although two years were the target training length for students to complete the program, based on our earlier experience with the control group, students exposed to the new method completed their training in less time (see Figure 4). The results showed a significant statistical difference between the lengths of time periods it took participants to complete the biotechnology training program, depending on which method was used. Sixty percent of students trained with the new method completed their training program within three months compared to 40% of those trained with the conventional method (see Figure 4). The remainder 40% of students trained with the new method completed their training within 9 or 12 months. Overall, the new method resulted in a maximum training period of one year, which was half of that required by most students trained with the conventional





method, and yet the new method resulted in students producing all publishable data in such the shorter time period (see Figures 1 and 4). Unlike the conventional method that was generally relaxed in dispensing primarily technical skills, the new approach emphasizes acquisition of both theoretical and technical skills for immediate application.

Non-quantifiable Benefits

The *Center for Biotechnology Research and Education* is the most prominent such unit in the field of biotechnology at Langston and has extensive experience in providing undergraduate science research experiences. All past and present trainees joined the program with no prior biotechnology experience. However, by the completion of their training, they had all acquired new knowledge and laboratory skills.

In addition to laboratory bench work, participants learned how to search for subject-specific background information using traditional and modern library skills. Once students passed the initial phase of uncertainty at the beginning of the program, they developed and accepted their new identity as scientists and independent thinkers and learners. In most cases this resulted in personal and academic growth, the acquisition of research skills, development of self-confidence, maturation, and development of capacity for independent research.

Although the impact of the new approach on academic performance was not a prime target of the experiment (and thus was not tracked in the study), there is evidence that the influence of undergraduate research persists and influences classroom behavior (Ward et al. 2002). In a survey seeking minority alumni's feedback, undergraduate research was generally perceived as broadening and transformative (Villarejo et al. 2008). This survey also emphasized that alumni in research careers, who had expressed no interest in research careers when they entered college, credited their undergraduate research experience with putting them on the track toward their research career.

Overall, participant students had the opportunity to hone their learning and skills in critical thinking and research inquiry directly from faculty field experts. This provided students with unique broad and deep understanding of the underlying science, in a way that inspires them to not only master bench skills but also join the field for specialization. Following individual experimental implementation and data collection and preparation, students improved their subsequent communication skills through preparations of posters and oral presentations; peer-reviewed manuscripts; journal clubs; and other outlets for research dissemination and networking. They also evolved from their initial competitive personalities to more mature investigators who understood the value of group discussion of protocols before beginning to conduct their experiments. In addition to encouraging networking and camaraderie, this encouraged slow learners to gain skills from faster learners and more experienced senior students without feeling intimidated (See Figure 5).

Over 99 percent of all past and present trainees have or are in the process of completing their undergraduate degrees, and over 75 percent of past students have entered graduate or professional schools. All students who have participated in this study are committed to applying to graduate school; some have already entered graduate programs. These results are consistent with previous research that found that students, who participate in undergraduate research, are more likely to complete their undergraduate degrees (Lopatto 2004; 2007; Nagda et al. 1998), as well as to clarify, refine, and reinforce their career choices (Seymour et al. 2004). Involving undergraduates in science research is an effective way of inspiring more of them to commit to science in graduate school and in their careers (Tobochnik 2001; Lopatto 2007; Hathaway et al. 2002). Indeed, all of our past trainees, who have entered graduate school, have entered science programs.

As more of the university's students apply for graduate school, it has been easier for us to write stronger letters of recommendation for students, who have completed our program's research training than for those who have not. In addition to enabling collaborations between our program and some of our graduates' graduate school mentors, our students' undergraduate research experiences allowed them to qualify for graduate fellowships *faster*, primarily, because of their specific research skills. There is also evidence that some of our students, who entered graduate school, were assigned specific-thesis-research topics on gene isolation because of their experiences in our program.

Conclusion

Ongoing studies show that the new approach applied by Langston University's Biotechnology Research and Education Program is more effective than the conventional method in providing undergraduates with research experience. Defying conventional wisdom, undergraduate participants with GPAs under 3.0, who were trained with the new method, were among the top performers. This underpins the premise of this study that there are potentially outstanding performers among minority students with GPAs under 3.0 who need to be given a better chance to succeed, through approaches that make up for inadequate earlier preparation for work in important STEM fields.

In addition to social skills and personal and academic growth, all participants benefited from gaining a spectrum of new knowledge and skills, ranging from laboratory bench experience to critical thinking, research inquiry, data collection and preparation, and oral and written presentations.

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Kanyand Matand
P.O. Box 1730
Langston University
Langston, OK 73050
Phone: 405-466-6131
Fax: 405-466-3138
kmatand@luresext.edu

Kanyand Matand, PhD is the founding director of the Langston University Center for Biotechnology Research and Education and an associate professor instructing in the Departments of Biology, Agriculture and Natural Resources, and Honors Program. He leads several research activities focusing on cell biology, biotechnology, and genomics, all of which provide year-round opportunities for intense undergraduate research experiences and mentorships to students that are underrepresented in the sciences, at Langston University. He has extensive experiences providing undergraduate research experiences and mentorships to minority students since 2000.

Ning Wu, PhD is a senior research scientist in the Center for Biotechnology Research and Education at Langston University, and joined the university in 2002. He has specialized in molecular biology and genomics. His research focuses primarily on functional genome studies of plant, animal, and human. In addition to conducting research, Wu is extensively involved in providing undergraduate science research experiences and mentorships, with classroom assistance, to students from underrepresented communities at Langston University.

Lisa L. Rollins, PhD is the chairwoman of the Department of Communication at Langston University. She received the 2008 Grand Award in the Creative Partnership category from the Council for the Advancement and Support of Education's Region III for her partnership between students in her undergraduate journalism courses and The Daily News Leader, a Gannett-owned newspaper. She also received the 2007 Business Adviser of the Year Award from INROADS Inc., an international organization dedicated to developing and placing talented minority youth in business/industry and preparing them for community leadership. In 2004, she was named the OWLS Professor of the Year by nontraditional learners at Middle Tennessee State University. A longtime member of the Society of Professional Journalists, Rollins currently serves on SPJ's national Awards & Honors Committee.