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Teachers' Participation in Research Programs Improves Their Students' Achievement in Science

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Research experience programs engage teachers in the hands-on practice of science. Program advocates assert that program participation enhances teachers' skills in communicating science to students. We measured the impact of New York City public high-school science teachers' participation in Columbia University's Summer Research Program on their students' academic performance in science. In the year before program entry, students of participating and nonparticipating teachers passed a New York State Regents science examination at the same rate. In years three and four after program entry, participating teachers' students passed Regents science exams at a rate that was 10.1% higher ($P = 0.049$) than that of nonparticipating teachers' students. Other program benefits include decreased teacher attrition from classroom teaching and school cost savings of U.S. $1.14 per $1 invested in the program.

U.S. high-school students perform less well in science, technology, engineering, and math (STEM) than students in other economically advanced countries do (*1–5*). This low performance of students in STEM and the relative paucity of U.S. students pursuing STEM careers led one of the authors (S.C.S.) to found Columbia University's Summer Research Program (CUSRP) (*6*). Other universities have implemented similar programs for STEM teachers (*7*), likely for similar reasons.

CUSRP's premise, like that of other research experience for teachers programs, is that experience in the practice of science improves the quality and authenticity of science teaching and thereby increases student interest and achievement in science. CUSRP differs from most STEM summer programs in the time that participants are engaged [16 weeks over two summers, supporting online material (SOM) text S1], in the intensity of professional development (1 day per week, SOM text S2), and in its focus on quantitative assessment of the impacts of teacher participation on student science achievement.

Each spring, the CUSRP's Advisory Committee selects 10 to 13 middle- and high-school science teachers [~90% from New York City (NYC) public middle and high schools] from a pool of 30 to 60 applicants. (See SOM text S3 for teacher selection criteria, table S1 for program costs, and tables S2 to S4 for demographics of applicants and participants.) Admitted teachers are appointed as Visiting Scholars at Columbia University. They receive a stipend of $6000 per summer and an e-mail account enabling them to use the university's libraries. To aid in the transfer of concepts and techniques learned at Columbia to their schools and students, teachers may request up to $1000 per year for classroom and/or lab supplies and equipment and for conference travel. Per university regulations (*8*), entering teachers are trained in laboratory safety and other areas as needed (SOM text S4).

Accepted teachers are referred to a Columbia University faculty member who has indicated a willingness to mentor a teacher and is working in an area of interest to the teacher. Both the teacher and his/her prospective faculty mentor must indicate their agreement to work with one another for CUSRP to confirm the placement (see SOM text S5). Each host laboratory receives $1000 per summer for teacher-related costs (table S1). With his/her faculty mentor's approval, a graduate student with whom a teacher worked during the summer may be paid by CUSRP for consulting with the teacher and for providing him/her with in-school assistance (SOM text S6). Total program costs for the two-summer program are $27,526 per teacher (table S1), which are funded by grants and gifts (*6*).

Teachers assemble for 1 day each week during the summer for professional development exercises, including seminars, science museum visits, demonstrations of science teaching and teaching materials, training in data-driven instruction and classroom transfer of science concepts and technologies, and teacher-led research presentations. CUSRP provides lunch on professional development days, thereby encouraging social and professional interactions that facilitate the coalescence of teachers into a professional learning community (*9*). By these means, CUSRP has developed academically prepared, experienced teachers with the laboratory and science experiment–management skills needed to affect students' science achievement.

Of the 145 teachers who completed the program from 1994 to 2005, 95 taught a Regents-level science course in a regular NYC public high school and therefore were eligible for the student outcomes study (table S5). The number of teachers available to participate in the study was reduced to 32 because of reassignments to teach a non-Regents subject, transfer to another school, lack of a nonparticipating teacher concurrently teaching the same subject, or a school-wide Regents exam waiver (SOM text S7 and tables S5 and S6). These 32 teachers were similar in race, gender, age, educational background, and teaching experience to the 145 teachers who completed CUSRP from 1994 to 2005 and the 95 who taught in NYC public high schools (tables S2 to S5).

From 1998 to 2002, CUSRP participated in a National Science Foundation–sponsored multisite study of science work experience programs for teachers (SWEPT), which encompassed teachers and students in more than 80 urban and suburban high schools in Arkansas, California, Georgia, Idaho, New York, and Washington. The study's results generalize to CUSRP (*10*). Thus, it is not surprising that we found rates of and reasons for teacher attrition similar to those reported by the SWEPT study (SOM text S7).

To assess program impact on teachers, CUSRP teachers were surveyed in the spring of their first and second years after program entry about their current professional activities. Their responses (Table 1) indicate that they implemented a number of new constructivist educational practices. A trained observer (*11*) repeatedly visited classes of one cohort of program participants and confirmed the accuracy of these self-reports (Table 1). Consistent with this observer's findings and our comment that the SWEPT study's (*10*) results generalize to CUSRP, a significantly ($P < 0.05$) higher percent-

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age of SWEPT teachers' students reported reflecting "on course material by writing in a notebook," using "primary sources such as journals," and being encouraged by their teacher to "think about a math/science career" than comparison teachers' students did (table S8) (*10*).

CUSRP teachers indicated that the stresses they experienced in adapting to a research laboratory increased their appreciation of their students' difficulties and prompted them to respond more sympathetically to them. Instead of judging students' answers as "right" or "wrong," they ask, "Why do you think that?" They gain the confidence to acknowledge gaps in their own knowledge. "That's a good question," they say. "I don't know the answer but I can help you find it."

As in other research experience programs (*12*), CUSRP participants reported that their experiences in the program elevated their interest in education and encouraged them to continue teaching. Accordingly, attrition rates were 2.3% per year for CUSRP graduates versus 6.3% per year for comparably experienced teachers nationally (SOM text S7 and tables S6 and S9).

To earn a New York State (NYS)–certified high-school diploma, students must score ≥65% on five NYS Regents exams, one of which must be in science. Hence, Regents are high-stakes exams on which students strive to do their best. We compared pass rates on Regents biology (termed "Living Environment" in NYS), chemistry, and earth science exams of 7209 students of CUSRP teachers with those of 36,101 students who studied the same subjects at the same time and in the same schools in classes of non-CUSRP teachers as a quantitative measure of the impact of teacher participation in CUSRP on student achievement (Fig. 1 and table S10).

In the year before CUSRP entry, 45.7% of CUSRP teachers' students passed (≥65%) a Regents science exam, essentially the same percentage as students of nonparticipating teachers (Fig. 1). In the first 2 years after teacher entry into CUSRP, their students' Regents science exam pass rates were not significantly different from those of nonparticipating teachers' students. In contrast, in the third and fourth years after teacher entry into CUSRP, their students' average Regents science exam pass rates were 10.1 percentage points higher than those of nonparticipating teachers' students (Fig. 1). This difference was significant ($P = 0.049$) by standard one-way analysis of variance (*13*) using SPSS software.

Overall, in the 4 years after each teacher's entry into CUSRP, an average of 15.5 more of her/his students passed a Regents science exam than nonparticipating teachers' students did (table S10, row 9). This stepwise improvement in Regents exam pass rate is the pattern that is expected after teacher adoption of new teaching methods and materials. It is consistent with Supovitz's report (*14*) that teachers take several years to translate professional development experiences into new educational practices.

Three lines of evidence indicate that these results were not influenced by systematic bias. First, pre-course cognitive tests and surveys administered to 4397 high-school freshmen and sophomores in biology and chemistry classes of study and comparison teachers participating in the national SWEPT study showed no significant differences in cognitive abilities, home educational resources, parental education, or student or parental educational expectations among the CUSRP teachers' students and those of nonparticipating teachers (*10*). Four hundred and seventy of these students were enrolled in Regents living environment or chemistry classes of 12 CUSRP and 12 comparison teachers in NYC public high schools. The sole significant ($P < 0.04$) difference among the NYC students was that more CUSRP than comparison teachers' students reported that their parents expected them to attend college. Thus, schools did not assign demographically or academically advantaged students to CUSRP teachers' classes.

Second, teachers whose students' Regents exam results make up the substantive data set (Fig. 1) taught at 24 different regular public high schools in all five NYC boroughs. The socioeconomic characteristics of students in these schools mirror those of NYC's public schools generally [71% are minorities underrepresented in science and 75% qualify for free lunch (*15*, *16*)]. That they were from disadvantaged backgrounds is manifest in their Regents science exam pass rates (Fig. 1), 11.5 to 13.4 percentage points less than the NYC-wide average for living environment, chemistry, and earth science (table S11).

Third, the study's design controlled for the most important variables [for example, teachers' and students' socioeconomic backgrounds, students' cognitive abilities, school environment, and curriculum (*10*)]. The use of Regents exams assured that students took tests seriously (*10*). Teachers' full-time, two-summers-long engagement precluded their participation in another sustained professional development activity in years one and two after entry into CUSRP.

Thus, teacher motivation remains the principal uncontrolled variable. Ideally, one would control for it by randomly assigning teachers to control and experimental groups. This would require two applicants of equivalent background and experience teaching the same subject in the same or similar high school per program opening. NYC's public school system is the nation's largest. Nonetheless, the number of qualified applicants was not sufficient to yield 20 applicants from the same or similar high schools annually. Therefore, random assignment was not an option.

Teachers who volunteer for two summers of immersion in research are probably highly motivated, increasing the likelihood that they will outperform their nonparticipating colleagues. Yet, in the year preceding CUSRP entry, we found no significant difference in Regents science exam performance of participating and nonpar-

Table 1. Responses to CUSRP's Spring Implementation Survey (table S7) of 46 (90%) of 51 teachers who participated in, or completed, the program in 2004 and 2005.

Responses
• 96% increased hands-on classroom activities and/or introduced new laboratory exercises.
• 93% developed new or revised content to lessons and/or laboratories.*
• 83% introduced new technologies in their class and laboratory exercises (e.g., chromatography, micropipettes, PowerPoint).
• 73% increased requirements for formal written and/or oral reports.
• 65% read scientific journals (e.g., *Science*, *Nature*) more frequently.
• 64% discussed science careers and related jobs with their students.
• 53% assumed new leadership roles/responsibilities in their schools or districts.

*361 standards-based lesson plans are currently on CUSRP's Web site (*6*).

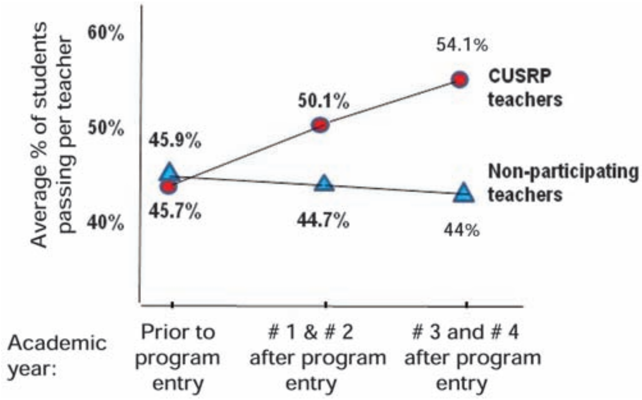

Fig. 1. Percent of CUSRP teachers' and nonparticipating teachers' students passing Regents examinations. Data are for 7209 students in living environment, chemistry, or earth science classes of NYC public high-school science teachers participating in CUSRP (red circles) and for 36,101 students studying the same subject at the same time and in the same high-school in a class taught by a nonparticipating science teacher (blue triangles) (see tables S2 to S5 for demographics of teachers and table S10 for the percent and number of additional students passing a Regents science examination per CUSRP teacher versus per nonparticipating teacher).

ticipating teachers' students (Fig. 1). This finding suggests that although teacher motivation probably contributes to their students' improved achievement, it does not predestine this outcome. The evidence suggests that the program's impact on teachers drives the improvements in student science achievement (Fig. 1 and table S10).

What elements account for the program's success? Clearly, the laboratory experience is one. In the sense that teachers work in different laboratories with different mentors on different research problems, each teacher's experiences are unique. What is common is that all teachers are treated as professionals, challenged to think independently and creatively, and engaged in studying an authentic contemporary scientific problem. This stretches teachers professionally and personally, sharpens their analytic and laboratory experiment–management skills, and enables them to better understand and communicate science concepts and practices.

The weekly day-long professional development workshops and the two-summer requirement also are critical for the program's success (SOM text S1 and S2). The workshops are weekly reminders that the program's purpose is to enhance teachers' abilities as science educators. The two-summer commitment ensures that teachers achieve competence and confidence in their lab experiment–management skills, which are attributes that characterize teachers whose students performed at the highest level on the *National Assessment of Educational Progress* 1996 (*17*) and 2005 (*18*) 8th-grade science tests. The authors of these studies concluded that such teachers are more likely to implement weekly science demonstrations and hands-on exercises than are teachers lacking these skills, and students who participate in such exercises weekly exhibit greater science achievement than students who participate in them less frequently or not at all. We suggest that the skills teachers acquire in science research programs are qualitatively distinct from, and complementary to, those acquired in most pre-service academic training. They encourage teachers to implement authentic science exercises that engage students' interest and stimulate them to inquire about the natural world. As one CUSRP teacher put it, "Before I entered this program, I taught about chemistry. Now I teach chemistry."

The increases in student science achievement and teacher retention provide immediate economic benefits to NYC's Department of Education (DOE) (tables S12 and S13) and longer-term economic benefits to society as a whole (*19*). NYC's high schools require students who fail a Regents exam to retake and pass it. At $2107 per student per course, we estimate that NYC's DOE saved $297,845 in summer school, course, and exam repetition costs for the 155 additional students who passed a Regents science exam of each cohort of 10 CUSRP teachers (table S12, row 2). CUSRP teachers are retained in education at a ~threefold greater rate than comparably experienced science teachers are (SOM text S7 and table S9). We estimate that in the 4 years after CUSRP entry of each cohort of 10 teachers, NYC's DOE saved $17,055 in teacher recruitment costs (table S12, row 3). Overall, we estimate that NYC's DOE saved $1.14 per $1 invested by CUSRP's sponsors (table S12, row 5).

Biology (Living Environment, chemistry, and earth science Regents exams are collectively the second-least-frequently passed Regents exams among NYC high-school students (table S11). If 10% of the 15.5 additional students of each CUSRP teacher who passed a Regents exam also earn a Regents high-school diploma, each CUSRP teacher will have produced 1.55 additional Regents high-school diplomates in the 4 years after program entry (table S12, row 6). The public economic benefits of high-school graduates exceed those of nongraduates by $209,100 (*19*). Thus, 1.55 additional high-school graduates generate tax revenues and societal cost savings of $282,841 (table S13, row 7), a return of $10.27 per $1 invested in CUSRP (table S12, row 8). CUSRP's overall return rate, therefore, probably falls between the $1.14 in immediate economic benefits and $10.27 in long-term economic benefits per $1.00 invested.

More than 28,500 students studied Regents-level Living Environment, chemistry, or earth science in classes of the 95 NYC public high-school science teachers (table S13) who completed CUSRP between 1994 and 2005. We estimate that during this period, 2339 (8.25%) (table S13) more CUSRP than non-CUSRP teachers' students passed a Regents exam in one of these sciences and that 15 more CUSRP than non-CUSRP teachers (table S13) were retained in classroom teaching. Accordingly, NYC's DOE saved $5.3 million in course repetition and teacher recruitment costs (table S13), or $2.01 per $1.00 that CUSRP's sponsors invested in the program. If in addition, 10% (234) of these students earned Regents diplomas, the United States will benefit from the ~$42.8 million (calculated as in table S12, row 7) in additional lifetime tax payments and health, welfare, and criminal justice cost savings they generate. CUSRP's ease of implementation, effectiveness, and individual and societal benefits have led to its adoption by Singapore's Ministry of Education (*20*). We suggest that it is a model for in-service science teacher professional development that significantly improves student science achievement.

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