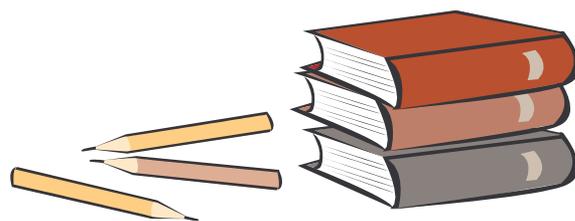PROFESSIONAL DEVELOPMENT

Who Is Responsible for Preparing Science Teachers?

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At the University of Colorado at Boulder, involving students in the transformation of science courses raises the visibility of science teaching as a career and produces K–12 teachers well-versed in science.

Teachers knowledgeable in both science and pedagogy are critical for successful math and science education in primary and secondary schools. However, at U.S. universities, too many undergraduates are not learning the science (1–3), and our highest performing students are choosing fields other than teaching (4). With a few exceptions [such as (5, 6)], universities convey that teaching kindergarten to 12th grade (K–12) is not a career worthy of a talented student (7). Two out of three high school physics teachers have neither a major nor a minor in the discipline (8), and the greatest teacher shortages are in math, physics, and chemistry. The shortages of teachers with these majors have likely contributed to the poor current outcomes (9) for math and science education [supporting online material (SOM) text].

The first of four recommendations by the National Academies for ensuring American competitiveness in the 21st century was to "increase America's talent pool by vastly improving K–12 science and mathematics education" (9). Teacher preparation is not solely the responsibility of schools of education. Content knowledge is one of the main factors positively correlated with teacher quality (10), yet the science faculty members directly responsible for teaching undergraduate science are rarely involved in teacher recruitment and preparation.

The Learning Assistant Model

At the University of Colorado (CU) at Boulder, we have developed a program that engages both science and education faculty in addressing national challenges in education. Undergraduate learning assistants are hired to assist science faculty in making their courses student centered, interactive, and collaborative—factors that have been shown to improve student performance (1–3). The program also recruits these learning assistants to become K–12 teachers. Thus, efforts to improve undergraduate education are integrated with efforts to recruit and prepare future K–12 science teachers.

Since the program began in 2003, we have transformed 21 courses (table S1) with the participation of 28 science and math faculty members, 4 education faculty members, and 125 learning assistants. The learning assistants support and sustain course transformation—characterized by actively engaged learning processes—by facilitating collaboration in the large-enrollment science courses (fig. S1). The program also increases the teacher-to-student ratio by a factor of 2 to 3 (SOM text). Without learning assistant participation, such courses tend to be dominated by the lecture format. Faculty members new to course transformation are supported by faculty that have experience working with learning assistants (SOM text).

About 50 learning assistants have been hired each semester for courses in six departments: physics; astrophysical and planetary sciences; molecular, cellular, and developmental biology (MCD biology); applied mathematics; chemistry; and geological sciences. The learning assistants are selected through an application and interview process according to three criteria: (i) high performance as students in the course; (ii) interpersonal and leadership skills; and (iii) evidence of interest in teaching. Learning assistants participate as early as the second semester of freshman year and as late as senior year. Learning assistants differ from traditional teaching assistants (TAs) in that learning assistants receive preparation and support for facilitating collaborative learning.

Learning assistants receive a modest stipend for working 10 hours per week in three aspects of course transformation. First, learning assistants lead learning teams of 4 to 20 students that meet at least once per week. Learning assistant–led learning teams work on collaborative activities ranging from group problem-solving with real astronomical data to inquiry-based physics activities. Second, learning assistants meet weekly with the faculty instructor to plan for the upcoming week, to reflect on the previous week, and to provide feedback on the transformation process. Finally, learning assistants are required to take a course on Mathematics and Science Education that complements their teaching experiences. In this course, cotaught by a faculty member from the School of Education and a K–12 teacher, learning assistants reflect on their own teaching, evaluate the transformations of courses, and investigate practical techniques and learning theory (SOM text).

Through the collective experiences of teaching as a learning assistant, instructional planning with a science faculty member, and working with education faculty, learning assistants develop pedagogical content knowledge, which is characteristic of effective teachers (11). The skills that learning assistants develop are valuable for teaching at all levels and in many environments. Those learning assistants who consider K–12 teaching as a career are encouraged to continue and are eligible for NSF-funded Noyce Teaching Fellowships (fig. S2).

Results of the Learning Assistant Program

The learning assistant program has successfully increased the number and quality of future science teachers, improved student understanding of science content, and engaged a broad range of science faculty in course transformation and teacher education.

To date, 125 math and science majors have participated as learning assistants and 18 of

| Undergraduates enrolled in science teacher certification programs			
Major	All of Colorado (2004–2005) LAs not included	CU Boulder (2004–2005) LAs not included	CU Boulder (2005–2006) LAs recruited
Physics and astrophysics	2	1	7
MCD biology	0	0	4
Chemistry	14	0	N.A.
Geoscience	11	0	N.A.

More students enticed into teaching. The learning assistant (LA) program at CU Boulder improved recruitment of undergraduate students into K–12 teacher certification programs relative to the undergraduate recruitment rates noted for 2004 to 2005 without the learning assistant program. Chemistry and geoscience joined the program in 2006, and so have not yet recruited students into teaching certification programs. N.A., not applicable.

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them (6 math and 12 science) have joined teacher certification programs. These learning assistants have an average cumulative grade point average (GPA) of 3.4, higher than the typical 2.9 GPA for math and science majors who express interest in teaching (12). In physics at CU Boulder, the average GPA for majors is 3.0, and it is 3.75 for learning assistants.

The learning assistant program improved recruitment rates to science teacher certification programs over preexisting rates (see table on page 445). Before the learning assistant program, about two students per year from our targeted science majors enrolled in certification programs. Nationwide, about 300 physics majors each year are certified to teach (13). Thus, even small improvements in recruitment rates could have an impact on the pool of available teachers, particularly in the state of
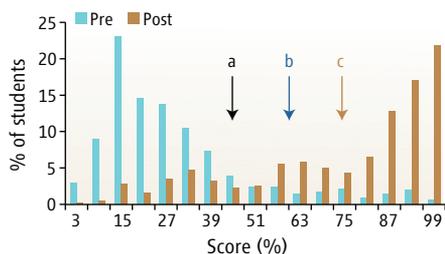
Learning assistants improve student learning. Pretest and posttest FMCE results for CU students in a transformed course with learning assistants. The pretest median is 24% (±1%) (n = 467); the posttest median is 85% (±1%) (n = 399). Arrows indicate posttest average (mean) scores for (a) students nationwide in traditional courses with pretest scores matching those of CU students, (b) students in a CU course that features educational reforms but no learning assistants, and (c) students in the CU course transformed with learning assistants (arrow shows the mean of the brown bars).

Colorado (14). Most of the learning assistants who decided to become teachers report that they had not explored teaching as a career until participating as learning assistants. Factors that led to decisions to become teachers include recognition of teaching as intellectually challenging and positive attitudes among participating faculty (7).

Development of Content Knowledge

Each of the participating departments demonstrates improved student achievement as a result of the learning assistant program (15–17). The transformation of the introductory calculus-based physics sequence provides an example. These courses are large (500 to 600 students), with three lectures per week implementing peer instruction and personal response systems (17, 18). The learning assistant program has provided enough staff to implement student-centered tutorials with small-group activities (19). Learning assistants and TAs

train together weekly to circulate among student groups and ask guiding questions. The number of applicants for learning assistant positions in physics is currently 50 to 60 per term for 15 to 20 positions.

We assessed student learning with the Force and Motion Concept Evaluation (FMCE) (20) and the Brief Electricity and Magnetism Assessment (BEMA) (21). In transformed courses, students had an average normalized improvement of 66% (±2% SEM) for the FMCE test (see chart, left), nearly triple national average gains found for traditional courses (3, 22). With the BEMA exam, the average normalized learning gains for students in the transformed courses ranged from 33 to 45%. National averages are not yet available for this new BEMA exam. The normalized learning gains for the learning assistants themselves average just below 50%, with their average posttest score exceeding average scores for incoming physics graduate students. In a different model, students enrolled in a physics education course can opt to participate as learning assistants for additional credit (23). These students make gains twice that of their peers who do not opt to participate as learning assistants. Students who engage in teaching also demonstrate increased understanding of the nature of teaching and improved abilities to reflect on their understanding of teaching and learning (23) (table S2).

Impact on Faculty

Faculty members participating in the learning assistant program have started to focus on educational issues not previously considered. Faculty members report increased attention to what and how students learn. In a study of faculty response to this program, all 11 faculty members interviewed reported that collaborative work is essential, and learning assistants are instrumental to change (7). One faculty member notes: "I've taught [this course] a million times. I could do it in my sleep without preparing a lesson. But [now] I'm spending a lot of time preparing lessons for [students], trying to think 'Okay, first of all, what is the main concept that I'm trying to get across here? What is it I want them to go away knowing?' Which I have to admit, I haven't spent a lot of time in the past thinking about." This type of statement is common among those who engage in course transformation for the first time (SOM text).

Sustaining Successful Programs

The learning assistant model can be sustained and modified for a variety of institutional environments. Another longstanding successful model, the UTeach program at the University of Texas (5) has demonstrated that it is possible to internally sustain educational programs for science majors. These and other model programs bring together partners who each have a vested interest in increasing the number of

high-quality teachers and the number of math and science majors, as well as improving undergraduate courses.

Implementation of a learning assistant program requires local interest from faculty in the sciences and education, as well as administrative backing and funding of a few thousand dollars per learning assistant per year (SOM text). The cost of a learning assistant is less than one-fifth that of a graduate TA. Learning assistants may also receive credit in lieu of pay. Another model is to fund learning assistant stipends from student fees.

With collective commitment, education can be brought to greater visibility and status, both for students considering teaching careers and for faculty teaching these students (SOM text). As scientists, we can address the critical shortfall of K–12 science teachers by improving our undergraduate programs and supporting interest in education.

References and Notes

1. J. Handelsman *et al.*, *Science* **304**, 521 (2004).
2. J. Handelsman *et al.*, *Science* **306**, 229 (2004).
3. R. Hake, *Am. J. Phys*. **66**, 64 (1998).
4. National Science Board, *Science and Engineering Indicators 2006* [National Science Foundation (NSF), Arlington, VA, 2006], vol. 1, NSB 06-01; vol. 2, NSB 06-01A.
5. UTeach (https://uteach.utexas.edu).
6. Physics Teacher Education Coalition (www.ptec.org).
7. V. Otero, paper presented at the AAAS Annual Meeting, Washington, DC, 17 to 21 February 2005.
8. M. Neuschatz, M. McFarling, *Broadening the Base: High School Physics Education at the Turn of the New Century* (American Institute of Physics, College Park, MD, 2003).
9. NRC, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Future* (National Research Council, Washington, DC, 2005).
10. U.S. Department of Education, Office of Policy Planning and Innovation, *Meeting the Highly Qualified Teachers Challenge: The Secretary's Second Annual Report on Teacher Quality* (Editorial Publications Center, Washington, DC, 2002).
11. L. S. Shulman, *Educ. Res*. **15**, 4 (1986).
12. L. Moin *et al.*, *Sci. Educ*. **89**, 980 (2005).
13. M. Neuschatz, personal communication.
14. Colorado Commission of Higher Education, *Report to Governor and General Assembly on Teacher Education* (CCHE, Denver, CO, 2006).
15. J. K. Knight, W. B. Wood, *Cell Bio. Educ*. **4**, 298 (2005).
16. M. Nelson, doctoral dissertation, University of Colorado, Boulder, CO (2005).
17. N. D. Finkelstein, S. J. Pollock, *Phys. Rev. ST Phys. Educ. Res*. 1, 010101 (2005).
18. E. Mazur, *Peer Instruction: A User's Manual* (Prentice-Hall, Englewood Cliffs, NJ, 1997).
19. L. McDermott, P. Shaffer, *Physics Education Group, Tutorials in Introductory Physics* (Prentice-Hall, Saddle River, NJ, 2002).
20. R. K. Thornton, D. R. Sokoloff, *Am. J. Phys*. **66**, 338 (1998).
21. L. Ding, R. Chabay, B. Sherwood, R. Beichner, *Phys. Rev. ST Phys. Educ. Res*. **2**, 010105 (2006).
22. The student normalized improvement is defined as (posttest − pretest)/(100 − pretest).
23. N. D. Finkelstein, *J. Sch. Teach. Learn*. **4**, 1 (2004).
24. This work is supported by the NSF, the American Institute of Physics, the American Physical Society, the American Association of Physics Teachers, and the University of Colorado. We thank the STEM Colorado team and the PER group at the CU Boulder for helping develop and maintain this effort.