

A physics department's role in preparing physics teachers: The Colorado Learning Assistant model

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In response to substantial evidence that a large portion of the U.S. student population is inadequately prepared in science and mathematics, we developed an effective and adaptable model for physics education that improves the education of all students in introductory physics and at the same time increases the numbers of talented physics majors getting certified to teach physics. We report on the Colorado Learning Assistant model and make evidence-based claims about its effectiveness at a large research university. Since its inception in 2003, we have increased the pool of well-qualified K–12 physics teachers by a factor of 3 or more, engaged scientists significantly in the recruiting and preparation of future teachers, and improved the introductory physics sequence so that students' learning gains typically double the traditional average.

I. INTRODUCTION: THE U.S. EDUCATIONAL CONTEXT

Undergraduate students in physics, including those who go on to become high school physics teachers, are not being adequately prepared. One need only look at political reports,¹ international^{2,3} or national⁴ studies, or research on student learning⁵ for evidence that we are missing our mark. Two out of three U.S. high school physics teachers have neither a major nor a minor in physics,⁶ and there are no subject matter specialties that have a greater shortage of teachers than mathematics, chemistry, and physics.⁷ Too many undergraduates are not learning the foundational content in the sciences^{8,9} and our higher-performing students are going into fields other than teaching.¹⁰ The effects are dramatic. For example, only 29% of U.S. eighth grade students scored at or above proficient on the National Assessment of Educational Progress in 2005. What is even worse is that only 18% U.S. high school seniors scored at or above proficient.¹¹ With few exceptions,¹² research universities are not seriously attempting to recruit or prepare physics majors for K–12 teaching careers. Moreover, universities are sending the message, usually implicit but often explicit, that such a career is not a goal worthy of a talented student.¹³

Recently, the National Academies listed four priority recommendations for ensuring American competitiveness in the 21st Century. The first of these recommendations, in priority order, was to “Increase America’s talent pool by vastly improving K–12 science and mathematics education.”¹ Who will prepare the teachers? Physics teacher preparation cannot be solely the responsibility of schools of education.¹⁴ Studies point to *content knowledge* as one of the main factors that is positively correlated with teacher quality;¹⁵ yet, those directly responsible for undergraduate physics content, physics faculty members, are rarely involved in teacher preparation.

II. THE COLORADO LEARNING ASSISTANT MODEL

At the University of Colorado at Boulder (CU Boulder), we have developed an adaptable model that engages both physics faculty and education faculty in addressing the national challenges in science education. Talented undergraduate physics majors are hired as *Learning Assistants* (LAs) to assist interested faculty in facilitating redesigned, large-enrollment introductory physics courses that place greater focus on student learning than on instructor teaching. We are redesigning our courses to employ the findings of research on student learning, to utilize nationally-normed and validated assessment instruments, and to implement research-based and research-validated curricula – those that are inquiry oriented and student-centered rather than teacher-centered.¹⁶ Toward this end, we implement *Peer Instruction*¹⁷ in lecture and *Tutorials in Introductory Physics*¹⁸ in recitations. Each of these pedagogical innovations has been demonstrated to improve student understanding of the foundational concepts in introductory physics. Studies show that when undergraduate courses are transformed to actively engage students in these ways, student performance is improved.^{8,9}

The Learning Assistant program in physics is part of a larger campus-wide effort¹⁹ to transform science, technology, engineering, and mathematics (STEM) education at CU Boulder, and currently runs in nine science and mathematic departments. The Colorado Learning Assistant program uses undergraduate courses as a *mechanism* to achieve four goals.

1. Course transformation: Improve the education of all science and mathematics students (K–16)
2. Recruitment: Recruit more and improve the preparation of future science and math teachers
3. Research: Engage science faculty more thoroughly in preparation of future teachers and discipline-based educational research
4. Culture: Transform science departmental cultures to value research-based teaching as a legitimate activity for ourselves and for our students.

In Fig. 1, these four synergistic goals are illustrated, and *Undergraduate Course Transformation* is highlighted because although it is itself a goal, it also serves as the central mechanism by which the other three goals are achieved within the Learning Assistant model.



Fig. 1. Synergistic goals of the Colorado Learning Assistant program.

Since the inception of the program (Fall 2003) through most current data analysis (Spring 2010), we have transformed over 35 undergraduate mathematics and science courses using LAs with the participation of over 48 science and mathematics faculty members including 2 Nobel Laureates and several National Academy members. A total of 696 LA positions have been filled by 449 individual LAs, (some hired more than once), 186 positions have been filled in physics and 123 in astronomy. In physics, more than 15 faculty members have been involved in transforming a course or in sustaining previous transformations.¹⁹ The program impacts roughly 2,000 introductory physics students per year and is still growing. Recent efforts are focusing on the transformation of upper-division courses.^{20,21} The LAs are instrumental in initiating and sustaining course transformation by taking active roles in facilitating small-group interaction both in large-enrollment lecture sections and in interactive recitation sections. Because these LAs also make up a pool from which we recruit new K-12 teachers, our efforts in course transformation are tightly coupled with our efforts to recruit and prepare future K-12 science teachers.

Each semester, the physics department typically hires 18 LAs from a pool of roughly 60 applicants. These LAs predominantly support transformations in the Introductory calculus-based Physics 1 and 2 sequence (for majors and engineers), but have also supported transformations in non-major introductory courses such as Light and Color, Sound and Music, and Physics of Everyday Life, as well as upper-division courses such as Electricity and Magnetism. In the Introductory Physics I and II courses, faculty members work with both undergraduate LAs and graduate Teaching Assistants (TAs) on a weekly basis to prepare them to implement research-based approaches to teaching and to assess the effectiveness of these instructional interventions. Participating faculty members also work with each other to work out bugs, to provide support and advice for implementing various innovations, to try new ideas, and to discuss their research findings regarding the course transformations²². Some of these research results are presented in the following section.

LAs engage in three major activities each week that support all three aspects of course transformation (Fig. 2). First, LAs assume one of two main roles to support changes in lecture-based courses: (1) leading novel recitation sections that focus on students working collectively to make sense of carefully designed and sequenced curriculum activities – the University of Washington *Tutorials in Introductory Physics*,¹⁸ (Fig. 3) or (2) working within the large lecture setting, where they facilitate group interaction, helping enrolled students engage in debates, arguments, and in forming consensus around conceptual questions that are posed roughly every 20 minutes of lecture, utilizing personal response systems (“clickers”) to poll the class. Second, the team of LAs from each department meets weekly with the faculty instructor of the transformed class to plan for the upcoming week, to reflect on the previous week, and to examine student assessment data in these courses. It is in these sections that TAs and LAs work collectively and develop a scholarly inquiry into the teaching and learning practice. Finally, LAs from physics (and from all participating STEM departments) attend a specialized course in the School of Education, *Mathematics and Science Education* that complements their LA-teaching experiences. In this course, LAs reflect on their own teaching practices, evaluate the transformations of courses, share experiences across STEM disciplines, and investigate relevant educational literature.

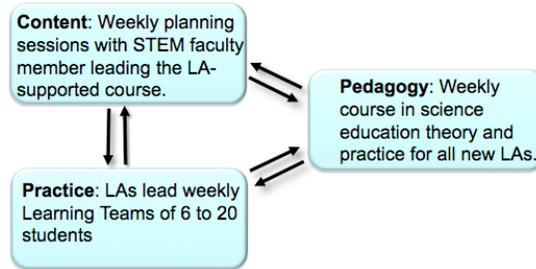


Fig. 2. The LA experience triad for developing pedagogical content knowledge.

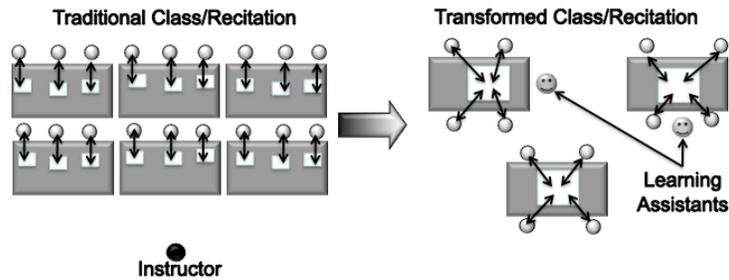


Fig. 3. Traditional versus transformed class setting.

Through the collective experiences of teaching as an LA, instructional planning with a physics faculty member, and reflecting on their teaching and the scholarship of teaching and learning, LAs integrate understanding of content, pedagogy, and practice, or what Shulman²³ calls *pedagogical content knowledge*, which has been shown to be a critical characteristic of effective teachers. Putnam and Borko²⁴ have demonstrated that pedagogical training is most effective when it is situated in practice—when teachers have the opportunity to try out and revise pedagogical techniques by implementing them with real students. This reflective practice is a standard feature of the LA program since LAs take their Math and Science Education course during the first semester in which they serve as LAs. Those LAs who decide to seriously investigate K–12 teaching as a possible career option are encouraged to continue as an LA for a second and third semester. Those who commit to becoming teachers and are admitted to our newly revised CU-Teach²⁵ teacher certification program are eligible NSF-funded Noyce Teaching Fellowships.²⁶

There are several elements that distinguish the Learning Assistant program from other programs that use undergraduates as teaching assistants. First, although course transformation is a key element of the of the LA program (which has significant impact on the learning of enrolled students), the target population of the program is the LAs themselves. The LA program is an *experiential learning program*; the learning is embodied in the *experience* of serving as an LA. Second, as stated above, the LA program serves as a K–12 teacher recruitment program. Throughout the LA experience, LAs learn about the complexity of problems involved in public science education and their potential roles in generating solutions to these problems. Although only approximately 12% of LAs are actually recruited to K12 teaching careers, the program is valuable to all students as they move into careers as research scientists, college

professors, or into industry and have opportunities to exercise their roles in improving science education more broadly.

III. RESULTS OF THE LA PROGRAM

The LA program has been successful at increasing the number and quality of future physics teachers, improving student understanding of basics content knowledge in physics, and engaging research faculty in course transformation and teacher recruitment.

A. Impact of LA program on teacher recruitment

Since inception in Fall 2003 through Spring 2010, 186 LAs positions have been filled in the physics department (120 individual LAs have been hired; 66 were hired for more than one semester) and 123 positions filled in the astronomy department (82 individual LAs hired; 41 hired for more than one semester). Of the individual LAs hired in physics and astronomy, 40 physics LAs were female and 45 astronomy LAs were female. Among the 82 individual LAs that were hired in physics, 68 were physics, engineering physics, or astrophysics majors, 45 were other STEM majors (such as mechanical engineering, aerospace engineering, and math), and among the remaining 7, 4 were open option and 3 were finance or communications. In astronomy, 27 of the 82 individual LAs hired were astronomy majors, 3 were physics majors, 17 were other STEM majors (such as aerospace engineering, mechanical engineering, and math), and 6 were open option. The remaining 29 LAs hired in astronomy were majors such as economics, international affairs, finance, political science, etc. This should be expected since some of our transformations take place in courses for non-science majors, which is one of the places from which future LAs are recruited. In some cases, students change their majors to STEM majors as a result of participating in the LA program. For example, a political science major who served as an LA in astronomy changed her major to biochemistry, became certified to teach secondary science, and is now teaching science in a local high needs school district. The average cumulative grade point average of physics majors was 3.6 (well above the department's 3.0 average) and 3.2 for astronomy majors. Sixteen physics and astronomy/astrophysics majors have been recruited to teacher certification programs (9 physics and 7 astronomy/astrophysics majors).

Table I demonstrates the impact of the LA program by comparing the total enrollments of physics/astrophysics majors in teacher certification programs in the entire state of Colorado in 2004–2005 (out of almost 11,000 certification students from 18 colleges and universities)²⁷ to current enrollment and certification data from students who entered the teaching profession through the LA program.

Table I. Production of K–12 science teachers majoring in physics/astrophysics.

Total physics/astrophysics enrollment in certification programs in state of Colorado AY 2004–2005	Physics majors enrolled in teacher certification programs from CU Boulder LA Program AY 2007–2008 ³⁸	Former LAs teaching (physics majors) AY 2007–2009	Total physics/ astrophysics LAs becoming teachers or future teachers as of Fall 2009
5	13	3	16

Prior to the LA program, CU Boulder was producing less than one physics teacher per year. The LA program is poised to triple the number of future physics teachers in the state of Colorado. Most of the LAs who have decided to become teachers report that they had not previously explored teaching as a career until participating as LAs. Our surveys of LAs¹³ indicate that one of the factors influential in helping students to consider teaching has been the encouragement and support of participating STEM faculty members. Another frequently reported reason for making the decision to become a teacher is the recognition of teaching as an intellectually challenging endeavor. A typical LA (Physics, Fall 2004) stated,

It would have been weird at first when I first started [to consider teaching].... But now [the LA program] is really affecting the way a lot of us think.... So now it's kind of a normal thing to hear, Oh yeah, I'm thinking about K-12 ... It's not out of the ordinary, whereas a couple years ago it would have been strange for me to hear that.

B. Impact of LA program on physics content knowledge

Students learn more physics as result of the course transformations supported by the LA program. In this section, we present sample results from our introductory calculus-based physics courses where most physics LAs are employed. These are large classes (500-600 students) with three lectures per week, implementing *Peer Instruction*¹⁷ and now include the *Tutorials in Introductory Physics*.¹⁸ The LA program was initially established in our physics department in 2003 due to one faculty member's (Pollock) intentions to implement the *Tutorials* after visiting the Physics Education Group at the University of Washington. At that time, the LA program was being piloted in four departments and Pollock took advantage of this opportunity to use undergraduate LAs alongside graduate teaching assistants. We therefore have no course transformation data that isolate the use of LAs (or TAs) from the implementation of the *Tutorials*. This type of isolation would be difficult because the *Tutorials* require a higher teacher to student ratio, which was made possible at CU Boulder through the LA program. Below, we report data from our course transformations using both LAs and *Tutorials* with the assumption that both have played a major role in enhancing student learning. We do not argue that LAs are more effective than graduate TAs when the *Tutorials* are used, although below we demonstrate the value that the LA experience has on LAs' themselves and on faculty using LAs.

Each semester, we assess student achievement in the transformed courses with research-based content surveys.

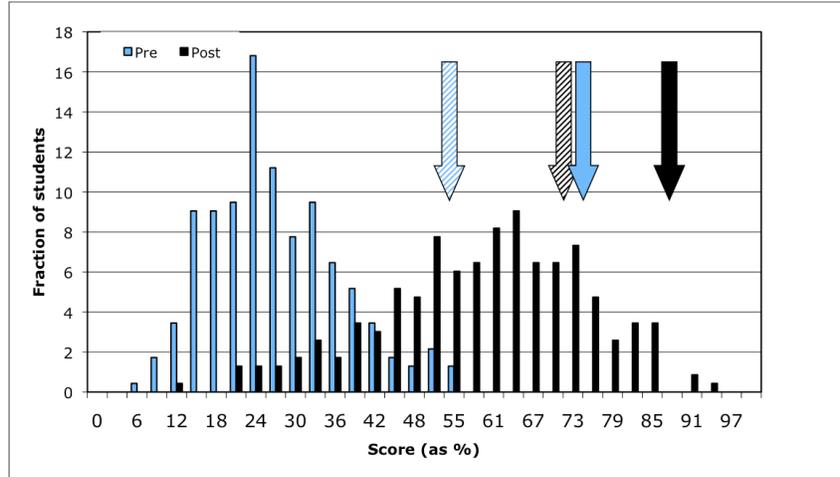


Fig. 4. Pre/Post scores on BEMA instrument for students enrolled compared to LA Histogram bars show data for students enrolled. Dashed arrows indicate LA Pre/Post scores *first* semester LAs were used. Solid arrows indicate LA Pre/Post scores averaged over subsequent semesters.

Specifically, we use the Force and Motion Conceptual Evaluation (FMCE)²⁸ in Mechanics (first semester) and the Brief Electricity and Magnetism Assessment (BEMA)²⁹ in Electricity and Magnetism (second semester). Figure 4 shows BEMA results for all of the students enrolled in second-semester introductory physics. These data have been replicated for subsequent semesters.²⁵

Figure 4 shows longitudinal BEMA data demonstrating that LA-transformed courses result in greater learning gains for enrolled students, and result in even greater learning gains for students who participate as LAs.³⁰ The histogram shows pre-scores (light bars) and the post scores (black bars) for the fraction of the 600-student class that scores in a particular range. The average post-test score for this term was 59% (which corresponds to a normalized learning gain of 0.45). (For comparison, a recent national study[ref Kohlmyer et al, "Tale of Two Curricula", Phys Rev STPER 5, 020105 (2009)] shows typical post-test scores in *traditionally* taught courses at peer institutions are significantly below our results - with reported post-averages around or below 45%, and normalized gains of 0.15-0.3) The dashed arrows near the top of Fig. 4 show the pre- and post-BEMA scores for LAs during the first semester that LAs were used (first-pass) in the physics department. All of these first-pass LAs had taken a *non-transformed* introductory electricity and magnetism course preceding their service as an LA. The solid arrows near the top of Fig. 4 show the average pre- and post-BEMA scores for LAs in the semesters after the first-pass, where all LAs were recruited from transformed classes. *That is, most of the LAs from the subsequent semesters had taken an introductory course that was transformed using LAs.* The average normalized learning gains for all students in the transformed courses have consistently ranged from 33% to 45%. The normalized learning gains for the LAs themselves averages just below 50%, with their average posttest score *exceeding* the average incoming physics graduate-TA's starting score. These data suggest that LA-supported courses are beneficial to students, and that LAs' scores increase

greatly after one semester of being an LA. In fact, by the end of one semester of being LAs, the LAs' scores are more like the graduate TAs' scores than those of non-LA peers.

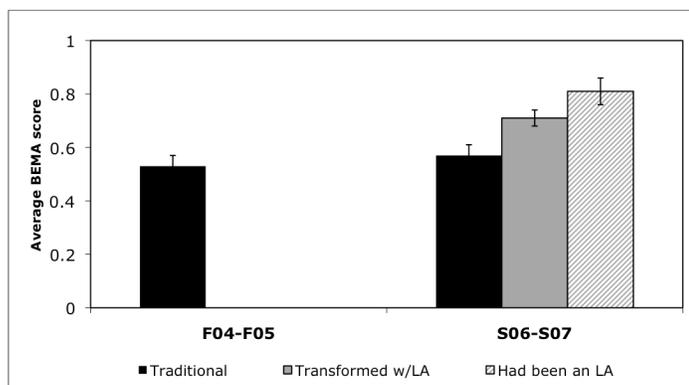


Fig. 5. BEMA scores of physics majors after taking upper-division Electricity and Magnetism, binned by semester and freshman (Physics II) background.

The BEMA data represented in Fig. 5 are scores of students enrolled in upper-division Electricity and Magnetism. The bin labeled “F04-F05” is the average BEMA score for students who were enrolled in upper-division E&M in the 2004–2005 school year. None of these students had enrolled in an introductory physics course that was transformed using LAs. The three bins labeled “S06-S07” represent the average BEMA score for three different groups of students who were enrolled in upper-division E&M during the 2005–2006 school year: (1) had a traditional introductory experience with no LAs, (2) those who took an introductory course that was transformed using LAs, and (3) students who had been LAs themselves. The scores of the students who did not take a transformed course are about the same in both F04–F05 and S06–S07. The students who had taken a transformed introductory E&M course scored higher than those who did not, and the LAs scored even higher than that. This suggests that the LA program produces students who are better prepared for graduate school and for teaching careers. These data also suggest that the LA experience greatly enhances students’ content knowledge.³⁰

In addition to increased content gains, LAs show strong evidence of attitudinal gains. The Colorado Learning Attitudes about Science Survey (CLASS)³¹ is a research-based and validated instrument intended to measure students’ attitudes and beliefs about physics and about learning physics. As is the case with the Maryland Physics Expectations Survey³² and other instruments of this type, students’ attitudes and expectations about physics tend to degrade over a single semester in universities throughout the nation.³² The arrows in Fig. 6 show results from a recent semester. First-semester physics students showed large negative shifts in their overall views about physics and in their personal interest as measured by the CLASS. The second semester course showed smaller negative shifts (possibly due to a combination of instructor and selection effects). Note that both of these courses were transformed and show high levels of conceptual learning. The LAs started with much more expert-like views and high personal interest, both of which increased greatly throughout one semester of serving as LAs.

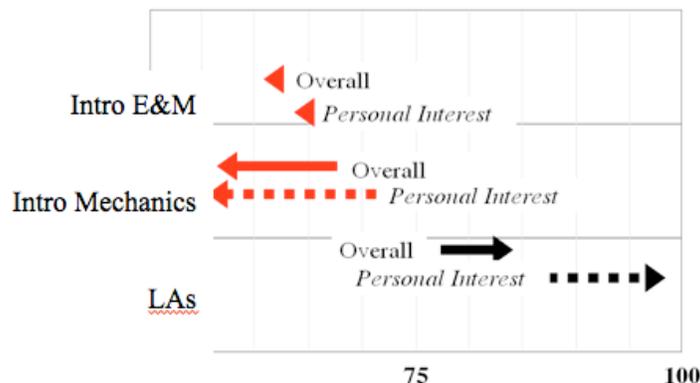


Fig. 6. Shifts by non-LA and LA students in attitudes about learning physics and in their personal interest in physics over one semester.

Although there is a contribution from selection effects associated with the LA data shown in Fig. 6, we see that during the semester that students are serving as LAs, they shift in a dramatically favorable manner. We also note that these students make up the pool from which we are recruiting future K–12 teachers. These students exit the LA experience with more favorable beliefs about science, greater interest in science and greater mastery of the content than their peers.

C. Impact of LA program on faculty

As a result of transforming courses and working with LAs, participating faculty members have started to focus on educational issues not previously considered. Faculty members report increased attention to student learning. All of the 11 faculty who were involved early in the LA program from 2003–2005 were interviewed and reported that collaborative work is essential, and LAs are instrumental to change. One typical 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 ‘OK, 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 statement was drawn from the group of faculty members who are now perceived by students as caring about student learning and supporting their decisions to become K–12 teachers. Impacts on faculty are also observed in the scaling of the program at CU Boulder. Increasingly, faculty members are working together to implement the LA program in the physics department as well as in other departments. Faculty members seek out one another for support and meet weekly in “Discipline-Based Educational Research” (DBER)³³ meetings to discuss their teaching and the use of LAs, and to present data from their assessments and evaluations of their transformations.

It is important to note that the Learning Assistant model does not stop at the introductory level. Faculty who teach upper-division courses are increasingly drawing on LAs to help them transform their courses, including third-semester Introductory Physics³⁴ and upper-level Electricity and Magnetism³⁵ and Quantum Mechanics. In these environments, faculty work with LAs (typically second- or third-time LAs or Noyce Fellows) to make small- to large-scale, research-based transformations to their courses. In these contexts, LAs assume varying roles, all with the common theme of supporting educational practices that are known to improve student understanding.

IV. SCALING THE LA PROGRAM

We have studied the scaling of the program within a department by examining the use of LA-supported *Tutorials in Introductory Physics* over a six-year span, covering 15 different implementations of Tutorials by 15 faculty members.²² We observe that it is possible to demonstrate strong and consistent learning gains for different faculty members. All except two of the courses listed in Table II were taught by different instructors. Semesters F03 and S04 were taught by the same instructor, a faculty member who also engaged in physics education research. All of the other faculty members who taught the courses listed in Table II vary from somewhat to vaguely familiar with physics education research.

Table II summarizes the overall measures of students' conceptual learning gains in first-semester courses. The table illustrates that while the courses listed span nearly the entire range of learning gains documented for interactive courses elsewhere,⁹ all courses with the LA-supported Tutorial experiences led to learning gains higher than any classes that had traditional recitation experiences. The data suggest that the transformations are transferrable among faculty members at the CU Boulder, even among faculty members who have little or no experience with physics education research. This finding in turn suggests that such LA-supported Tutorials are transferable to faculty at other institutions.

The development of an LA program in physics departments at other institutions requires the commitment of dedicated faculty and administration within the department. Currently, at least five universities throughout the nation are funded to emulate the Colorado LA program as a part of their work with the Nationwide Physics Teacher Education Coalition.³⁶

Many other institutions of which we are aware are also emulating the Colorado LA model. Although the Colorado LA program is a campus-wide program spanning 9 departments, other institutions have successfully developed and managed LA programs at their campuses within the physics department alone.³⁷ Successful LA programs have started within the physics department with a buy-in from the department chair and a handful of interested faculty members.

Table II. Normalized gain on the FMCE for first-semester Introductory Physics taught by different instructors.

Semester	Recitation	N (matched)	Average posttest score	Normalized gain $\langle g \rangle$
F01	Traditional	265	52	0.25
F03	Tutorials	400	81 (FCI data)	0.63
S04	Tutorials	335	74	0.64
F04	Workbooks	302	69	0.54
S05	Traditional	213	58	0.42
F05	Traditional	293	58	0.39
S06	Tutorials	278	60	0.45
F06	Tutorials	331	67	0.51
S07	Tutorials	363	62	0.46
F07	Tutorials	336	69	0.54

Departments considering implementing an LA program need to identify sources of financial and pedagogical support for the undergraduates who will be enrolling. Implementation of an LA program at an institution requires funding of a few thousand dollars per LA, per year.³⁸ An alternative to the financial costs is to provide course credit in a service-learning model,³⁹ where students opting to become LAs receive course credit for time spent supporting course transformation. While pedagogical support for LAs may be potentially challenging, we know it to be a critical component of the program. LAs must be supported *both* in weekly content preparation such as the Tutorial preparation described above and in their acquisition and implementation of pedagogical techniques through a forum such as the Mathematics and Science Education course. We encourage physics departments to partner with their Schools of Education to offer such a specialize course, and have sample course materials available for those interested. Some physics departments, typically those that have hired PER faculty members, are now offering a course on Teaching and Learning Physics^{40,41,42} that can be tailored to this purpose (and simultaneously provide course credit in a service-learning model).

V. SUSTAINING SUCCESSFUL LA PROGRAMS

Can the Learning Assistant model be sustained? Is it possible to scale this model without significant external funding? We believe so. Currently, 85% of our LAs are funded by our administration and private donations, although these are temporary funds and the university is working toward stable institutional funding.

At the CU Boulder, the Learning Assistant program is a school-wide program, and it benefits from such scale. We bring together a variety of interested faculty members, department heads, deans, and senior administrators, each of whom has a stake in and benefits from increasing the number of high-quality teachers, improving our undergraduate courses, and increasing the number of math and science majors. Because teacher recruitment and preparation are tied to the improved education for all students through the transformation of undergraduate courses, many members of the university

community have vested interest in the success of the Colorado LA program. CU Boulder recently received funding to replicate the University of Texas at Austin's successful UTeach certification program.⁵⁵ The new CU-Teach certification program utilizes the Colorado LA program as one of two methods for recruiting students to careers in teaching.

With the commitments of physics departments to the enhanced education of all students and to the recruitment and preparation of future teachers, we collectively may effect change to enhance the status of education, both for the students considering teaching careers and for the faculty teaching these students. As scientists, we can take action to address the critical shortfall of science teachers by improving our undergraduate programs and engaging more substantively in evidence-based solutions in education, and teacher preparation.

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