Adding some lab time is good, adding more must be better: the benefits and barriers to *lab-centric* courses.

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Abstract: This paper examines the benefits that can arise from increased use of labs in computer science instruction. While some use of labs is widespread in the earliest computer science courses, lecture and other "hands-off" time dominate. We have designed and run lower-division courses that successfully implement lab-centric instruction, in which the instructor contact time with students is either wholly or predominately through structured lab time. We talk about the benefits that lab-centric instruction can offer, our experiences with it, the factors constraining the adoption of lab-centric instruction at other institutions, and ways of overcoming these constraints.

Keywords: CS education research, CS 1, CS 2, closed laboratories, collaboration, tutoring.

1.0 Lab-augmented instruction

A course that implements *lab-augmented instruction* can be defined as a course that requires students to attend a "closed lab": a regularly scheduled, two- to three-hour session where a group of students work under supervision toward completion of a set of tasks designed specifically for use in the lab. This can be contrasted with "open labs," in which attendance and tasks are left up to the students. In some institutions, the supervision is performed by teaching assistants (usually graduate students), while at other settings full-time instructional staff supervise the sessions.

Augmenting computer science courses with closed lab has long been advocated. The claimed benefits of closed labs include more experimentation and inquiry, facilitation of student community and collaboration, and positive and improved student attitudes and interest ([1, 2] discuss closed labs across the sciences; [3]). There are not many good metrics for success of labs (however, see [4, 5]), but claims of better learning are sometimes made. Closed labs are widespread in the early CS courses; McCauley [6] conducted surveys showing approximately 75% and 50% usage in CS1 and CS2 respectively.

2.0 Lab-centric instruction: definitions and benefits

A lab-centric format differs substantially from its more traditional counterpart, with students as well as staff taking on new educational roles. Instead of playing a secondary role to in-class lectures or discussions, the lab sessions are the *primary* resource for student learning. Lectures and discussions, where provided, arise from and supplement the lab content rather than vice versa. Table 1 below details the differences between lab-augmented and lab-centric courses.

Lab-centric courses have many potential benefits:

- The passive learning in lecture and recitation sections is replaced with active, hands-on learning (two prominent advocates are [7, 8]).
- Frequent embedded assessments keep students apprised of their progress and understanding. With the increased measures, instructors can engage in one-to-one and group tutoring sessions at precise moments that students are forming misconceptions, without disrupting learning for other students. Tutoring is considered the best instructional method for learning and works without extensive instructor training [9, 10].
- Many activities in lab-centric instruction can be collaborative, either on- and off-line, which provide a myriad of benefits [11, 12]. One activity we use often is a "gated collaboration" in which a student, after answering a question, can review the responses of their classmates. This fosters engagement across the students in the class.
- With the greater number of activities in lab-centric courses, lab work can be structured to increase in difficulty and complexity at a gradual, measured pace. This provides scaffolds for learning, and contrasts starkly with the significant jumps in complexity between lab exercises, homeworks, and projects in many traditional courses.

Traditional (lab-augmented) course	Lab-centric course
The student attends 2-3 hours per week of lecture.	The student attends 0-1 hours per week of lecture.
The student works through a set of short exercises, perhaps with a partner, in 2 hours per week of lab.	The student works through a wide variety of exercises in 5-7 hours per week of lab.
The student attends 1 hour per week of "discussion", in which examples similar to upcoming homework exercises are covered.	Students engage in structured collaboration activities; occasional impromptu discussions may arise in lab with a neighboring student, or between lab instructor and a group of students.
The student works on homework, not always clear about skills and techniques that need to be applied. Help, when available, is found through a class newsgroup, fortuitously scheduled teaching assistant office hours, or communication with fellow students.	Most exercises formerly done as homework are now completed in lab. Relevant context is clear from earlier exercises. Help from instructors is always available in the lab section.

Table 1: Comparison between traditional and lab-centric courses, from a student's perspective.

- Lab-centric courses can offer a much wider variety of activities than their traditionally taught counterparts, supporting a wider variety of prior knowledge, learning styles, and abilities.
- The lab-centric format fosters more efficient interaction with staff. Students ask questions in the context of the day's lab activities, rather than out of context during office hours or after lecture.
- For most staffing arrangements, lab-centric courses are generally neutral with respect to workload. In large-enrollment courses with multiple sections run by teaching assistants (TAs), the reduced lecture time frees up the instructor to spend on activities such as TA training and review of student work. Designing materials the first time can be time consuming, however. For TAs, increased supervision time is offset by eliminating office hours and reducing preparation requirements. In courses with a single instructor and a single section (*e.g.*, small liberal arts colleges, and community colleges), the small increase in supervision time is offset by reduced preparation time for lectures.
- In the best lab-centric settings, the classroom climate is cooperative and relaxed, and student learning is the main focus. Class can take on a seminar-like quality, with collaborative yet supervised progress towards goals. Certainly, this is rare in large introductory programming courses!

While our lab-centric courses at Berkeley have all been in the lower-division (as well as the majority of lab-augmented courses offered elsewhere), lab activities are appropriate in every area and at every level of computer science [13]. Supervised lab exercises are appropriate whenever students acquire and solidify understanding of computing agents (languages, applications) through computational models, learn and use implementation techniques in an environment, evaluate artifacts constructed in an environment, and do any kind of scaffolded design or reflection.

3.0 Our Experiences with lab-centric courses

At U.C. Berkeley and U.C. Merced, a total of five different lab-centric CS1 and CS2 courses have been offered. At Berkeley, our introductory programming course for non-majors and our CS2 in Java have been very successful, and have been offered multiple times. We use a home-grown web-based learning environment (the UC-WISE system, [14]), although many different learning environments could also support lab-centric instruction.

We have noted several benefits, although we have formally investigated only some of these:

- Students enjoy the course. In the first U.C. Berkeley lab-centric course, in summer 2002, students gave the instructor and teaching assistant much higher evaluation ratings than they had typically received in the past; for instructors in subsequent semesters who have instructor ratings from traditionally formatted courses this trend has continued, albeit to a lesser degree. Institutional measures of satisfaction with the courses remain high. In our own end-of-semester surveys we ask students a variety of questions about their satisfaction with the course. Most complaints center around the technology and the length or difficulty of the materials, while students generally like the flexibility and variety of the materials and the support given by the TAs.
- Students seem less reluctant to ask questions and engage the TAs and instructor. One student noted that in traditionally formatted classes, she felt that the TA's answers to her questions wasted the time of her classmates, while that wasn't the case in the lab-centric version. We have our teaching assistants make efforts

towards fostering a community in the lab room, from devoting much of the first session towards ice-breaking activities to actively bringing students together when they are having similar difficulties or questions with the activities. TAs who have taught multiple sections and/or semesters report that these activities do have a positive effect on student-TA interaction, even though there is a large variance between student groups no matter what is done.

- The quantity, variety, and breadth of materials can uncover subtle student misconceptions. In some cases previously unrecognized areas of confusion are revealed (*e.g.,* Ryan [15]). The sheer amount of data that students generate as they work through lab materials forces TAs to make choices as they try to assess student progress and understanding. It isn't uncommon, unfortunately, for some to ignore the student-generated data as much as possible, and simply wait for student questions. To reduce this, we require TAs to take time to grade a "quiz" that starts each day's activities. We have identified additional lab activities that are efficient at measuring aspects of student understanding, and have prototyped tools to help TAs monitor student progress through the session.
- Comparisons of student learning are difficult to make between lab-centric and traditional courses, but students seem to do at least as well in the lab-centric, and there is evidence that they do better in certain ways. Performance on duplicated final-exam questions are about the same.

  This is most true for students that would do poorly in the traditional course. Females, often at a disadvantage, seem more successful in lab-centric courses, perhaps because the more frequent opportunities for self-evaluation [16] and closer interaction with TAs. For instance, females scored about as well as males on their projects in one lab-centric semester of CS2, while in the next, traditionally formatted semester of the course, females did worse. (Exam scores showed the same trends across the two courses: females did worse.) Comparisons between minorities and non-minorities showed the same relationship, with a reduced effect size.
- Evidence has shown other interesting differences. In the two CS2 courses reference above, self-reports of procrastination were significantly lower in the lab-centric version – its structured labs may have been a cause of this. We have also noted that outside-of-course support services (at a central student learning center) have been cut for our CS1 course, which has been offered in a lab-centric format since spring 2003. Reduced use of the services was the cited cause.

As we scaled up to larger courses early on, it became apparent that close management of student progress through the course was important, especially with head instructor contact hours (via lecture) so infrequent. On one hand, the pervasive lab materials allowed students to have greater control over their own pacing through the course, which they appreciated. If pacing diverged widely, however, student on-line and face-to-face collaboration correspondingly diminished. And, if students reduced attendance in the scheduled lab sessions, opportunities for finely targeted and timely tutoring were lost, as well as for student to student interactions. We have succeeded in keeping our lab-centric courses more synchronous through a variety of methods, including small changes in grading to reward timely lab attendance; emphasis on "keeping-up" with the course, via active monitoring of student progress through the on-line materials; and efforts to increase cooperation and collaboration in the lab, for instance through team-building exercises, restricting "IPods", and the like.

4.0 Barriers to adoption of lab-centric instruction

Lab-augmented instruction in computer science is mainly a feature of introductory courses, and while widespread in those courses is not as universally adopted as in physics, chemistry, biology, and engineering curricula outside CS [6]. This adoption has taken some time [1], and it is reasonable to believe that adoption of lab-centric formats will be slowed by barriers similar to, although not identical to, those faced for lab-augmented instruction.

Shortage of facilities: With what might be significantly more scheduled lab time, some institutions will have trouble providing rooms with networked computers. With nationwide problems of reduced enrollments, however, this is effect will be mitigated, but enrollments are sure to rise again. There are few easy solutions to this problem, outside of the shifting that occurred during record large enrollments (laboratory sessions running late into the night, and so forth).

It should be noted, however, that future trends will minimize this barrier: with more students owning laptops and having institution-wide wireless network access, any meeting space can be used as a "lab" room.

Shortage of staff: With increased contact hours, staff shortages are a barrier to the adoption of lab-centric courses. This barrier acts quite differently for different institutions, however. In large-enrollment courses with multiple sections run by teaching assistants (which is what we have experience with), there is no increase in workload, assuming the course materials do not need major amounts of development. This was discussed in section 2 above.

These formats are typical of large institutions with graduate programs.

A second common course format has a single instructor leading a single section of students (say, fewer than 25). We call this the "good-shepard" instructional model: all of the students' supervision and instruction, be it lecture, lab, or office hours, comes from a single instructor. These courses sometimes meet entirely in lab rooms (i.e., where computers are present). This type of course is common in community colleges, small liberal arts schools, high schools, and upper division courses at most institutions. However, large institutions like Carnegie Mellon and the University of Waterloo opt for this format for their CS1 offerings.

In this format, instructors can incorporate lab-centric practices relatively easily. For instance, if the total contact hours for a traditional good-shepard course is five hours (three one-hour lectures and a two-hour lab), a switch to a single one-hour lecture and four hours of lab is workload neutral. And, if reduced lecture preparation is taken into account, additional lab-hours can be included.

A third common format poses the largest barriers to adoption: courses where faculty teach large multi-section lab or lecture courses without teaching assistants. The are common at large institutions that have no graduate program to provide teaching assistants. In an effort to adopt lab-augmented instruction, some of these institutions opt to hire several full-time instructors to lead the lab portion of the course while maintaining a single, large lecture (commonly, the lecture and labs are different courses that must be taken at the same time). In this situation, reducing the lecture time reduces the workload for a single instructor, while increasing the lab time increases the workload for many instructors. Lecture is the most efficient form of instruction from the perspective of staff workload.

Widespread adoption of lab-centric courses in these institutions will likely require changes in staff composition, although lab-centric curricular changes (*e.g.*, more collaborative exercises to help students teach one another) could partially alleviate these shortages. It should be noted that these institutions have made deliberate staffing choices in order to provide faculty supervision for their closed labs. Should lab-centric formats prove more successful than closed-labs staffed by full-time instructors, these institutions could change the composition of their staff again.

Satisfaction with status quo: There are still numerous CS departments with *no* experience with structured labs. Especially in upper-division courses, there are few alternative models to emulate. Moreover, lab-centric formats are new and untested, a concern to both individual faculty and institutions.

Instructors at these institutions claim that their students are learning just fine. How do they know? The confusion and blind alleys that students encounter in homework are almost invisible to instructors who teach in a traditional system. Moreover, the preference for the *status quo* ignores the current nationwide problems of reduced enrollment, especially among populations traditionally at risk (women, minorities).

Student inconvenience: While many students appreciate the lab-centric format, some students find the extra attendance requirements inconvenient. Even with similar workloads, students in a traditionally-formatted course can choose when and where to do more of the work than lab-centric students. Note that the time a student spends in lab in lab-centric computer science courses is comparable to lab time in a variety of courses in biology and chemistry.

In course with our home-grown system UC-WISE, however, students gain flexibility due to the fact that our lab materials are all available on-line, and can be reviewed or made-up as the student sees fit. It's likely that most, if not all, lab-centric courses will use an on-line content management system that offers the same benefits to students.

Determination of teaching credit: Informally, many consider lecturing as the core (if not entirety) of a professor's instructional work. It is also likely that many institutions use hours of lecture when determining faculty workload and teaching credit. With reduced lecture-hours, some administrations might move to lab-centric instruction for efficiency reasons—to get instructors to teach more courses—much as they have recently adopted distance learning formats. This is certainly not our motivation.

In lab-centric courses, lecture is partly replaced by a variety of other instructor activities that can receive increased attention, including curricular development and refinement, staff training, monitoring of student progress and understanding, surveying (and analysis) of students, and so on [14]. It is important to realize that these activities are crucial for student *and* institutional success, and should be considered central to a professor's duties both informally and formally.

High buy-in cost: Creating lab-centric courses is labor intensive. Developing and refining up to 7 hours of weekly materials is daunting, although most of what students do in existing courses can be integrated into a lab-centric course. With the wealth of materials, more attention needs to be paid to balance: between production and reflection; between coding, debugging, and analysis; and so forth. These are instructional design skills that may be underdeveloped in instructors.

As the use of lab-centric formats increases, the community can work towards easing the high buy-in cost. For instance, repositories of lab-centric materials can be maintained that ease searching and importing from common delivery platforms. Forums should be developed where novice instructors can get advice and assistance, and even teacher training workshops.

5.0 References

[1] Hofstein, A. & Lunetta, V.N. (2003). "The Laboratory in Science Education: Foundations for the Twenty-First Century", *Science Education*, 8(1), 28-54.

[2] Psillos, D. & Niedderer, H. (editors). (2002). *Teaching and Learning in the Science Laboratory*, Dordrecht, The Netherlands: Kluwer.

[3] Parker, J., Cupper, R., Kelemen, C., Molnar, D., & Scragg, G. (1990). "Laboratories in the Computer Science Curriculum", *Computer Science Education*, 1, 205-221.

[4] Ma, J. & Nickerson, J.V. (2006). "Hands-On, Simulated, and Remote Laboratories: A Comparative Literature Review", *ACM Computing Surveys*, 28(3), article 7.

[5] Soh, L-K., Samal, A., & Nugent, G. (2005). "A Framework for CS 1 Closed Laboratories", *ACM Journal of Educational Resources in Computing*, 5(4), article 2.

[6] McCauley, R. & Manaris, B. (2002) "Report on the Annual Survey of Departments Offering CSAC/CSAB-Accredited Computer Science Degree Programs", http://www.cs.cofc.edu/~mccauley/survey/.

[7] McKeachie, W.J. (2005). *Teaching Tips* (12th edition). Boston, MA: Houghton Mifflin.

[8] Bransford, J. D., Brown, A. L., & Cocking, R. R. (editors). (1999). *How People Learn: Brain, Mind, Experience, and School*. Washington, DC: National Research Council.

[9] Bloom, B. S. (1984). The 2 sigma problem: The search for methods of group instruction as effective as one-to-one tutoring. Educational Researcher, 13, 4-16.

[10] Chi, M., Siler, S., Jeong, H., Yamauchi, T., & Hausmann, R. (2001). Learning from Human Tutoring. Cognitive Science, 25, 471-533.

[11] Johnson, D.W., Johnson, R.T., & Smith, K.A. (1991). *Cooperative Learning: Increasing College Faculty Instructional Productivity*, ASHE-ERIC Higher Education Report No. 4, Washington DC: The George Washington University.

[12] Hoadley, C.M. (2004). "Fostering Productive Collaboration Offline and Online: Learning from Each Other". In *Internet Environments for Science Education*, M.C. Linn, E.A. Davis, & P.L. Bell (editors). Mahwah, NJ: Lawrence Erlbaum Associates.

[13] Tucker, A. (editor). (1991). Computing Curricula 1991: Report of the ACM/IEEE-CS Joint Curriculum Task Force. Association for Computing Machinery.

[14] Clancy, M.J., Titterton, N., Linn, M.C. Ryan, C., & Slotta, J.D. (2003). "New Roles for Students, Instructors, and Computers in a Lab-based Introductory Programming Course", *ACM SIGCSE Bulletin*, 35(1), 132–136.

[15] Ryan, C. (2006). "Analogies Are Like Bowling Balls, or Why Analogies to English Need Some Explanation to Help Students Learn Scheme", Technical Report No. UCB/EECS-2006-75, Berkeley, CA: EECS Department, University of California.

[16] Barker, L.J. and Garvin-Doxas, K. "Communication in Computer Science Classrooms: Understanding Defensive Climates as a Means of Creating Supportive Behaviors" ACM *Journal of Educational Resources in Computing*, volume 4, number 1, March 2004, article 1.