Effective Closed Labs in Early CS Courses: Lessons from Eight Terms of Action Research

Elizabeth Patitsas
University of Toronto & University of British Columbia
40 St George St.
Toronto ON M5S 2E4
patitsas@cs.utoronto.ca

Steven Wolfman
University of British Columbia
2366 Main Mall
Vancouver BC V6T 1Z4
wolf@cs.ubc.ca

ABSTRACT

We report on best practices we have established to teach first-year computer science students in closed laboratories, founded on over three years of action research in a large introductory discrete mathematics and digital logic course. Our practices have resulted in statistically significant improvements in student and teaching assistant perception of the labs. Specifically, we discuss our practices of streamlining labs to reduce load on students that is extraneous to the lab's learning goals; establishing a positive first impression for students and TAs in the early weeks of the term; and effectively managing the teaching staff, including weekly preparation meetings for TAs using and a gradual, iterative curriculum development cycle that engages all stakeholders in the course.

Categories and Subject Descriptors

K.3.2 [**Computers and Information Science Education**]: Pedagogy, education research

General Terms

Design, management

Keywords

Computer science education, curriculum development, curriculum evaluation, teaching assistants, labs, survey

1. INTRODUCTION AND MOTIVATION

The practice of having students taught in a laboratory setting, known as "closed laboratories"[1], "labs", or "practicals", came to prominence in the 1990s after the Denning report [3]

---

[1]We define a closed lab as a structured problem-solving session in a university facility—usually with specialized equipment—that is: required, synchronous, collocated, and facilitated.

recommended them. Among other hopes, CS educators believed these labs might dramatically improve interest in and perception of CS [13].

Unfortunately, a closed laboratory can also dissuade students from continuing in a major [12], as we also experienced. Specifically, if students perceive that a laboratory does not contribute to their learning, they are less likely to persist in the program [12]. Four years ago, students in our introductory discrete mathematics and hardware course complained of irrelevant and confusing subject matter, ill-prepared teaching assistants, and difficult yet unenlightening labs. The following year, we began our research to improve the course's laboratory component.

In this paper, we present key practices developed from our successful 3.5-year iterative refinement and assessment program for the course's closed labs. This paper is a follow-up to our previous one [14] and focuses on our high-level findings, including an additional year of data collection and analysis. Our changes aimed to improve student perception of the quality and relevance of labs. Our recommended practices therefore improve students' self-perceived learning and satisfaction with labs.[2]

The three sets of best practices we recommend in the remainder of this paper stand out from among many interventions we have attempted in meeting several criteria: (1) we have substantial longitudinal evidence to support their efficacy, (2) they generalize beyond the idiosyncrasies of our first-year discrete mathematics/digital logic course, and (3) they scale well to large courses.

1.1 Related Work

Deacon and Hajek [5] performed a six-semester study of student perceptions of the value of university physics labs. They found the four greatest factors on student perception were: pressure to complete labs within the allotted time, quality of the information in the written lab manuals, help provided by the teaching staff, and students' level of preparedness. Our work agrees with their findings: we found streamlining labs to reduce time pressure and clarify the written lab manuals and pre-lab work to be vitally important, as was effectively managing and preparing the teaching staff so they could be more effective in helping students.

---

[2]Consistent with the literature on student perception of learning [6] and our own observations, we do not believe that these changes have negatively impacted student learning, but we have only anecdotal evidence of positive impact.

Iterative curriculum development has played a central role here. Jones [9] lists five conditions that promote and sustain changes in the curriculum, all of which are satisfied in our work: mutual trust amongst stake-holders; committed and consistent leadership; proceeding with a non-threatening, incremental pace of change; professional development for academic staff; and effective motivation of curriculum developers. The best practices presented in this paper pertain only to the first four of these conditions, and assume motivation for improving labs for students and teaching staff.

2. CONTEXT OF THE COURSE

Our first-year course at the University of British Columbia has a hybrid curriculum of discrete mathematics and digital logic. Lectures topics include finite state machines, propositional and predicate logic, proofs, and some digital logic; however, the labs focus on digital logic, both simulated and physical. The course is a pre-requisite to the second year theory and systems courses, and takes our CS1 as a co-requisite. Approximately 300 students take the course annually, mostly first-year CS students.

The weekly lab sessions are two-hours long, and capped at 25 students. A pair of teaching assistants (TAs) run each session. Labwork is divided into "pre-lab" work, to be completed before arriving at the lab and graded upon arrival, and "in-lab" work, to be completed during the lab session and graded as it is completed.[3].

The course is taught by 1–3 instructors and about 7–15 TAs. Roughly half the TAs are undergraduates who excelled in the course themselves. The remaining (graduate) TAs typically have strong backgrounds in discrete mathematics but weaker backgrounds in digital logic, particularly breadboarding. Together the authors (a TA and an instructor) were on the course staff during every term of our research except one.

3. OUR APPROACH TO THE LABS

In action research, we act simultaneously as designers, instructors, and assessors of the course. With our iterative approach, our curriculum development and assessment methodology evolve over time. As such, we give here a brief description of the key long-term structures responsible for curriculum development and assessment of the labs' success. Where iterative changes are important in later sections, we mention them explicitly.

We solicited formal and informal feedback from all involved stakeholders. We gather informal, ad hoc feedback through talking to students, TAs and instructors. Our formal instruments now include surveying students after each lab and at the end of the term, and surveying TAs at the end of the term. Additional supporting data came from instruments focused on other parts of the course, particularly the mid-term and final course evaluations. These observations are used to inform the next cycle of development of the research, following the action research process to cyclically plan, act, observe, and reflect [11].

The weekly surveys occur at the end of the labs. We began this in summer 2010, the fourth term of this project. Students rate the following on a 5-point Likert scale:

Q1: I had enough time to work on this lab.

Q2: The written instructions were clear and well-written.

Q3: The lab was relevant to the lecture material.

Q4-7: The lab was {interesting | challenging | rewarding | fun}.

Q8: The lab was an effective learning exercise.

And then there are two open-ended questions:

Q9: What did you like most about the lab?

Q10: How do you think the lab could be best improved?

The end of term surveys for the students and TAs are analogous, and ask about how the labs went over the full course of the term. We started these surveys in spring 2009. The questions for the students are:

Q1-3: The {labs | pre-labs | challenge questions} contributed to my understanding of the course material.

Q4: The labs were related to the rest of the course material.

Q5: The labs were marked fairly.

Q6-10: The labs were {interesting | challenging | rewarding | fun | well-organized}.

Q11-12: I liked working with the {Magic Box[4]|circuit simulator[5]}

After Q3, Q5, Q10 and Q12, students had open-ended comment boxes inviting them "Feel free to comment on any of the above questions:", to elaborate on how they had answered the quantitative questions. There are then three additional open-ended questions:

Q13: What were your {favourite|least favourite} labs? Why?

Q14: How well did the labs integrate into the lectures? Did the labs help you understand the lectures?

Q15: The labs were intended to be done in pairs. Did you work in a pair? A group of three? How was this for you?

Q16: Do you have any other comments or suggestions about the labs? Did you like them?

For the end of term TA survey, some questions were reworded to ask for their perception of how the students found the labs (e.g. "The labs contributed to my students' understanding of the course material"). At this time, TAs also annotate copies of the terms' labs, commenting on what went well and what should be changed for the next term. Revisiting the labs this way also focuses TAs' survey responses.

The weekly student surveys are analyzed on a weekly basis, with summaries made of the qualitative feedback. The end of term surveys are analyzed at the end of every term; quantitative trends are examined across terms, and qualitative feedback are encoded for comparison between terms.

4. LESSONS FOR EFFECTIVE LABS

In this section, we present three sets of lessons (best practices) for effective labs. We ground the lessons by describing how they arose in our practice and provide the evidence—both quantitative and qualitative—that convinced us of their importance.

---

[3]The labs also feature optional bonus questions at the end, called "challenge problems"

[4]the breadboarding kits

[5]Until the end of 2010: TKGate; afterwards: Logisim

4.1 Streamline Labs

Lesson: Streamline labs to reduce the extraneous load [4] of the students.

In the weekly student surveys, we found that whether students "had enough time to work on this lab" was a crucial factor in their satisfaction, a statistically significant predictor of how "fun", "interesting", and "rewarding" the lab would be perceived. To give students enough time on the labs, we streamlined them in several ways: crafting a usable grading scheme that makes the students' goals clear (section 4.1.1), clarifying and hewing to our own intended learning goals (section 4.1.2), and eliminating obstacles that contributed to none of these goals (section 4.1.3).

One change we made to the labs early in this process was to reduce their length: aiming for labs to take 100 minutes to complete in the two-hour lab sessions [14]. This shift reduced the stress on students and TAs, allowing them to focus on the lab at hand, rather than the pressures of time.

4.1.1 Clarify the Grading Scheme

Lesson: Design the grading scheme to be clear, public, and accepted by all stakeholders.

Unclear lab grading schemes are frustrating for students and correspond with increased attrition rates [12]. When we began our changes to the labs in 2008, the grading schemes for the labs were private to the TAs and heterogeneous across labs. Informal feedback from students and staff meeting comments from TAs indicated the scheme was unclear to both parties and disorganized; students wasted valuable lab time (theirs and the TAs') worrying about grading issues.

Thus, we began clearly marking required tasks in each lab by prefacing them with a bold "**TODO:**". We continued streamlining the grading scheme (in 2009) by standardizing on a single, public rubric for all labs.

In the new rubric, TAs graded students holistically, with the goal of promoting analysis and creativity in the labs, and had levels such as *"Students completed the lab with clear analysis that is consistent with their data. . . [and] show[ed] creativity and insight. . . that goes beyond expectations."* and *"Students completed some significant part of the lab . . . On questioning by the TA about specific cases with incomplete work or rough analysis, the students indicate a plan for polishing the work given significantly more resources."*

However, TAs found the scheme difficult to interpret and apply consistently, and they pushed back strongly. Many TAs began grading for completion instead. This was a lesson for us: that all stakeholders *must* be involved and motivated in changes to the labs.

As a compromise between our goals and practical usability, six of the eight points in the labs are now for completion of the tasks labeled "**TODO:**" (including one point for the weekly survey); the other two points of eight remain targeted at analysis and creativity.

With continued feedback from students and TAs, these latter two points became more clearly defined, first as lists of suggested tasks and eventually as two "further analysis questions", each marked with a "**TODO (further analysis):**". These pose open-ended design and analytical questions about students' work. These questions require students to reflect on their work—such as comparing and con-
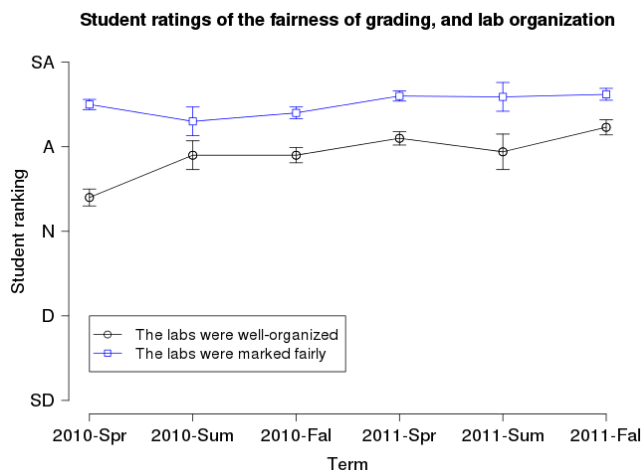

Student ratings of the fairness of grading, and lab organization

Figure 1: The holistic scheme was used in the first shown term; subsequent terms used the "further analysis question" approach and its revisions.

trasting circuit designs, thinking about applications of their work, or relating different concepts they had used.

The further analysis questions fulfill our goals of promoting higher-level thinking in the lab by engaging students in analysis and design. They fit into the consistent format of the lab; making grading less subjective and more practical for TAs, and clear to students. TAs also indicate that they enjoy these "further analysis questions", as they lead to deeper discussions with students. And as shown in Figure 1, students rate the labs as more organized than in 2009, when we began with the analysis marks. More significantly, surveyed TAs now statistically significantly agree more with "I felt comfortable marking my students."

4.1.2 Write the lab to its goals

Lesson: In writing a lab, first decide the intended tasks of the lab. Then write the lab to support these tasks, avoiding interesting details that are irrelevant to the lab's goals.

An unexpected result of labeling all gradable tasks as one of "**TODO (pre-lab):**", "**TODO:**", or "**TODO (further analysis):**" was to shift our lab design paradigm to a goal-oriented one, a long-advocated but oft-overlooked style [15, 7]. When writing new labs, or revising old ones, we began to write our labs by *first* deciding what each of the ten TODO tasks should be – and *then* writing up the rest of the lab to support those tasks.

A result of the new goal-oriented design was labs that were more focused, and more streamlined. We produced labs with less text, particularly "seductive detail": i.e. material that is interesting but not relevant to the instructional goal. It was thus clearer to students what was expected of them, and these expectations were better scaffolded [14]. Indeed, work in the education literature has shown us that "seductive detail" decreases learning [10].

As we reduce text, we have found it valuable to illustrate the labs with more figures and sometimes links to helpful animations. The increased use of diagrams has been particularly helpful for our students with poor English comprehension skills, traditionally the weakest group of students in

the labs. To help this group, we have also used readability indices as a guide for improving either entire labs, or sections of labs, for readability. End of term survey data from the TAs on "the labs were well-written" has had statistically significant improvement since 2009.

With less text in the lab manuals, we also began adding whitespace after each TODO task for students to fill in their own work. We have been generous in the amount of whitespace we give students, and have found that they appreciate having enough space to do their work in the manual directly. We have also made a point of making the whitespace proportional to the amount of work expected for the TODO task, further communicating our expectations to the students.

We also worked to cut extraneous activities. We previously reported trying "discussion periods" to encourage group discussion in each lab section [14], but we later cut these due to the amount of time they required.

4.1.3 Reduce Extraneous Difficulties

Lesson: With each lab's goals identified, you can now search for, and defuse, the sources of greatest pain for students that are unconnected to your goals.

Just as we worked to reduce extraneous *words* in the lab writeup [14], we have also begun focusing on reducing extraneous *difficulties*. We now regularly search out and address sources of "pain" for students that do not advance our learning goals. We discover these problems from students—who are vocal about problematic elements in survey responses and informal discussions, sometimes about difficulties that contribute little to learning—and from TAs—who we ask weekly about particular or unusual difficulties students have.

Central to our efforts has been to improve the lab equipment and its management: a breadboarding kit known as "The Magic Box" and a circuit simulator.

As we have described previously, students initially bought their "Magic Boxes", but we switched to lab-owned and managed kits [14]. Our survey data now show a dramatic positive shift in student perception. Rather than wanting to get (and feeling disappointed for not getting) their "money's worth", students were free to enjoy breadboarding for what it was. In student surveys, the visual, immediate feedback of the "blinking lights" is a commonly praised by the students.

We saw a similar shift in 2010 when we changed circuit simulators from TKGate [2] to Logisim [1]. As shown in Figure 2[6], TKGate was not very popular, particularly in comparison to the Magic Box. With the switch to Logisim in 2010W2, we saw a dramatic jump in student ratings of the circuit simulator. Both students and TAs prefer Logisim for its better usability, pared-down interface, and compatibility with multiple operating systems.

We are now looking at improving the breadboarding experience. Students often complain of the difficulty of reading the labels on the 74LS series chips, particularly when they search through boxes of unsorted chips. We plan to simplify this by painting over the most commonly used chips' labels to colour-code them. Presently, we do this for an early lab exercise, where students are given "mystery chips" with the labels painted over, and they are tasked with identifying the chips. Afterwards, the students have a tendency to hoard

[6]For more of our data, see `http://www.cs.toronto.edu/~patitsas/sigcse/sigcse2012_appendix.html`
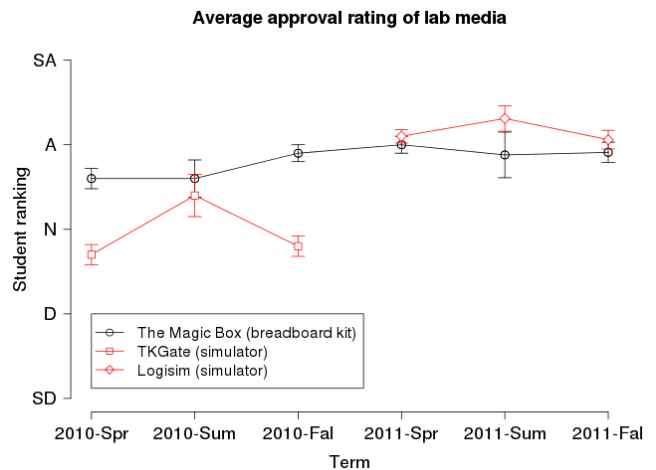

Figure 2: End of term student survey responses to "I liked working with the {Magic Box|circuit simulator}", showing a jump from TKGate to Logisim.

the painted chips for use in later labs, finding these easier to use than the provided magnifying glasses!

4.2 Making a Positive First Impression

Lesson: Identify and reduce extraneous complexity in the earlier weeks, allowing students to focus on the tasks at hand.

Student and TA feedback indicated the importance of making the first lab of the term welcoming to students, setting an expectation that labs would be fun, creative, and exploratory. As we noted in previous work [14], we had introduced a scaled-down version of the last lab—an exploration of a working CPU simulation—as the first lab of the term, with the aim of telling an overarching story in the course. Unfortunately, we found that a fully functional CPU in the first lab overwhelmed students.

Based on TA feedback, we tried moving the introductory lab on the CPU to the second week, returning the first lab of the term to being an introduction to basic logic gates. Complaints continued about the introductory CPU lab even after pushing it back a week – one TA wrote that *"[My least favourite lab was] CPU simulation, lab 3 or 4. very vague and students didn't know what they're doing."*

From discussions with students and TAs, it emerged that the problem was the overwhelming nature of a complete CPU. Working with TAs, we produced a stripped-down version of an ALU, as shown in Figure 3. Students still got a taste of the story of the course, and this version has gotten no complaints from students in the after-lab survey unlike previous terms, where it was a common student complaint.

Meanwhile, our first lab of the term, that on basic logic gates, was getting complaints that it did not give them enough training in how to use the breadboards, nor was a gentle enough introduction. For example, one TA wrote in the end of term survey, *"debugging huge magic box circuits was no fun. we could spend some time in the first a couple of labs to make sure students learn how to build circuits step by step. Perhaps, we can have an example circuit building step by step guide."* – and student feedback agreed: *"Make the*
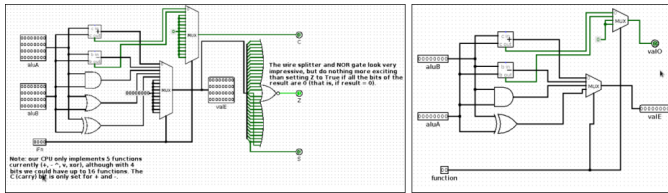
Figure 3: On the left, the complex Y86 ALU module from spring 2010; on the right, the pared down ALU from summer 2010. Both are too small to read details but still illustrate why the former was too confusing for students early in their first term.

labs more accessible, as in, try teaching with simpler circuits and approaches. The current labs are like following a step by step instruction of an overly complex manual which you can follow but not understand." The students had a clear preference for starting off breadboarding, since as one student wrote, *"The Magic Box is very tactile and rewarding."*

After an extended conversation about this with a few students, the lab coordinator wrote up a new introductory lab, giving students a gentler learning curve, illustrating most key steps with photos, and harnessing the students' motivation to play with the oft-praised "blinking LEDs". The new lab also featured an icebreaker activity, and greater opportunities for students to collaborate in the lab.

After adding the newer, gentler introduction to breadboarding in fall 2010, we saw a noticeable improvement in how students ranked the breadboarding kits, as shown in Figure 2. TA feedback is that students are now more comfortable with breadboarding, although work remains on how to better equip our students with debugging skills. Student feedback about the lab was overwhelmingly positive: *"I really liked the introduction and the ice breaker as we got to know the TA's and the other students in the class. I also liked learning how to use the clock to control LED's"* and *"[My favourite part was] Bread boarding. I enjoyed wiring up our own system of flashing lights."*

4.3 Improving Organization of TAs

Lesson: Prepare TAs together to establish a consistent level of preparation, and a community of support amongst the teaching staff.

As noted in previous work, we have found it critical to hold weekly meetings of the lab TAs—separate from our full staff meetings—wherein they complete the upcoming lab as if they were students and discuss how they plan to teach it [14]. Our analysis of TA and student survey data now reinforces the importance of this decision. As one TA noted in the TA survey, *"the lab TA meetings shortened the amount of prep time I needed to prepare for each lab"*—useful for managing the limited hours TAs have to work. These meetings ensure all TAs prepare to at least a consistent, sufficient level.

Furthermore, better-prepared TAs need less time to figure out complications or difficult problems in the lab and more time facilitating students' work. The community that the weekly lab TA meetings foster is hugely important for knowledge transfer between TAs, not only improving the teaching experience for them, but giving them support to grow as teachers. This supports greater "pull transfer" between TAs, which is known to be more important in knowledge transfer between educators [8].

The TAs were overall quite satisfied, and in the TA survey, would readily provide examples of enjoying themselves. Some examples include: *"Definitely challenging, and a large amount of work, but rewarding after having talked to some of the students at the end of the term."* and *"It was fun to build the counter[7] in two different ways, and comparing the two really helped the students' understanding."*

The lab TA meetings initially lasted one hour per week but later expanded to an hour and a half. Meetings early in the term often stretch to two hours to accommodate the greater training overhead. Even with the expanded time-slot, some TAs remain hungry for longer meetings; e.g. *"I would have liked more discussion on the further analysis questions in the lab meetings."* Practically, however, we recognize the need to achieve the goals of these expensive—in staff time—meetings efficiently and see this as future work.

Another lesson we learned painfully was that the instructors must communicate the vital importance and *mandatory* nature of these meetings early to lab TAs. Before we made this a matter of routine, absenteeism was a problem, but the lab coordinator (always a TA for us, and often an undergraduate TA) lacked the authority to enforce attendance. On the other hand, the intentional absence of the *instructors* at these sessions—besides saving instructor time—also encouraged TAs to provide candid feedback that never arose at full staff meetings.

Since refining the process of running the weekly meetings, we have found the course to run more smoothly for TAs and instructors, and students rate the labs as being more organized in the end-of-term surveys. As we see in Figure 1, students rate "The labs were well-organized" statistically significantly higher now. Furthermore, the end of term TA surveys have had significant gains in how interesting and fun they find the labs, how useful they find the meetings, and how comfortable they feel marking their students.

4.3.1 Improve Organization for TAs
Lesson: Establish a development cycle which is iterative, and incorporates feedback from all stakeholders in the course.

TA preparation is doomed to failure when the labs themselves are ill-prepared. We have therefore established a careful intra- and inter-term cycle of preparation and development on the labs. At the intra-term level, the timeline is driven by the need to post the lab manual at least one week in advance of the first lab session that uses it, so that students can practically complete the pre-lab work and to communicate that the pre-lab requirement is serious. At the inter-term level, we incorporate feedback from students, TAs, and instructors into iterative improvements in each lab and the arc of the labs as a whole.

A TA in the role of "lab coordinator" manages the curriculum development cycle. We have established a repository of documents for the coordinator to aide in this process: two—one aimed at planning development and one at managing TAs—lay out key tasks and timelines, and a third documents the history of feedback and comments on labs. The coordinator also updates these documents each term.

---

[7]A type of digital circuit used for counting.

The cycle of development and management proceeds as follows. Students write a short survey about their impressions of the lab as they complete it. At the next lab TA meeting, the lab coordinator debriefs the TAs about the lab[8]. The lab coordinator uses these data and their own notes when redrafting the lab for the next term. The coordinator sends an early draft to the instructor, for feedback and to ensure the lab is in harmony with the instructor's vision for the course[9]. Next, at the weekly lab meeting, the TAs give feedback that leads to further revisions, which both improves the lab and gives the TAs a sense of ownership. To accommodate that revision cycle, the meeting is two weeks before the lab is first used, or one week before the deadline for posting the lab. Students then write the lab, and the cycle begins again. Any given lab meeting sits at two points on this cycle: prospective and retrospective.

5. CONCLUSIONS

After 3.5 years of action research on this course, we have learnt three sets of generalizable lessons about the management and teaching of closed laboratories. Our changes have statistically significantly improved student perception of the labs, including self-reported learning. Further, the lab teaching assistants also report higher satisfaction and better preparation to teach the labs.

The first set of lessons is *to streamline the labs to reduce the extraneous load on the students*. This includes cutting down lab manuals in terms of words, particularly "seductive detail". In writing a lab, first identify its goals and the tasks to satisfy them. Then, write the rest of the lab instructions to support those goals, avoiding extraneous detail. Having identified the goals in each lab, search for and defuse the sources of greatest pain for students that are unconnected to those goals. Design the grading scheme to guide students' work toward the labs' goals; to admit clear and consistent interpretation by all stakeholders (students, TAs, and instructors); and to be acceptable in practice by those stakeholders. And, as with other elements of the course, eliminate extraneous complexity in grading.

Our second group of lessons is *to particularly target the earlier weeks* to start students and TAs on better footing and establish the desired atmosphere in the labs. Start students off gently—for us, introducing the equipment—in a way that promotes creativity and exploration. We found specifically that previewing the full story of the course early in the term could work, but only with aggressive simplification and careful attention to student motivation.

Our final set of lessons was *to effectively manage the teaching staff*. Prepare TAs together every week, creating a community of support for the teaching staff. This intra-term cycle of preparation can also form an integral part of the inter-term curriculum development cycle. Between terms, establish an iterative development cycle that incorporates feedback from all stakeholders in the course, ensuring long-term buy-in and success of curriculum development efforts.

6. ACKNOWLEDGMENTS

---

[8]The lab coordinator also runs one or more labs for firsthand experience and to get informal feedback from students.
[9]The draft is often accompanied by advice about how to link the course of the labs to the course of the lectures.

7. REFERENCES

[1] Logisim. http://ozark.hendrix.edu/ burch/logisim/.

[2] TKGate. http://www.tkgate.org.

[3] D. E. Comer, D. Gries, M. C. Mulder, A. Tucker, A. J. Turner, and P. R. Young. Computing as a discipline. *Commun. ACM*, 32:9–23, January 1989.

[4] T. de Jong. Cognitive load theory, educational research, and instructional design: some food for thought. *Instructional Science*, 38:105–134, 2010. 10.1007/s11251-009-9110-0.

[5] C. Deacon and A. Hajek. Student perceptions of the value of physics laboratories. *International Journal of Science Education*, 33(7):943–977, 2011.

[6] D. Dunning, K. Johnson, J. Ehrlinger, and J. Kruger. Why people fail to recognize their own incompetence. *Current Directions in Psychological Science*, 12(3):83–87, 2003.

[7] A. Fekete and A. Greening. Designing closed laboratories for a computer science course. *SIGCSE Bull.*, 28:295–299, March 1996.

[8] S. Fincher and J. Tenenberg. Warren's question. In *Proceedings of the third international workshop on Computing education research*, ICER '07, pages 51–60, New York, NY, USA, 2007. ACM.

[9] E. A. Jones. Special issue: Transforming the curriculum: Preparing students for a changing world. *ASHE-ERIC Higher Education Report*, 29(3):1–101, 2002.

[10] R. E. Mayer, E. Griffith, I. T. N. Jurkowitz, and D. Rothman. Increased interestingness of extraneous details in a multimedia science presentation leads to decreased learning. *Journal of experimental psychology Applied*, 14(4):329–339, 2008.

[11] R. O'Brien. An overview of the methodological approach of action research. *Theory and Practice of Action Research*, 1998. English version.

[12] C. O'Neal, M. Wright, C. Cook, T. Perorazio, and J. Purkiss. The impact of teaching assistants on student retention in the sciences: Lessons for TA training. *Journal of College Science Teaching*, 36(5):24–29, 2007.

[13] B. C. Parker and J. D. McGregor. A goal-oriented approach to laboratory development and implementation. In *Proceedings of the twenty-sixth SIGCSE technical symposium on Computer science education*, SIGCSE '95, pages 92–96, New York, NY, USA, 1995. ACM.

[14] E. Patitsas, K. Voll, M. Crowley, and S. Wolfman. Circuits and logic in the lab: toward a coherent picture of computation. In *WCCCE '10: Proceedings of the 15th Western Canadian Conference on Computing Education*, pages 1–5, New York, NY, USA, 2010. ACM.

[15] B. E. Walvoord, V. J. Anderson, T. A. Angelo, and V. J. Anderson. *Effective Grading: A Tool for Learning and Assessment*. Jossey-Bass, 1998.