A Case for Smaller Class Size with Integrated Lab for Introductory Computer Science

Kristy Elizabeth Boyer
Computer Science

Rachael S. Dwight
Computer Science

Carolyn S. Miller
Computer Science

C. Dianne Raubenheimer
Engineering Academic Affairs

Matthias F. Stallmann
Computer Science

Mladen A. Vouk
Computer Science

North Carolina State University
{keboyer, rsdwight, miller, dianne_raubenheimer, matt_stallmann, vouk}@ncsu.edu

ABSTRACT
Prompted by changes in the numbers and demographics of students enrolled and being retained in computer science, the Department of Computer Science at NC State University is revising its undergraduate curriculum to better meet the needs of its students, and increase student attraction and retention. One set of changes concerns introductory computer science courses (CS1). This paper reports on a study conducted to assess the impact of class size and active learning in our CS1 courses. We find that smaller classes with integrated laboratories improve both learning and retention, as well as satisfaction of the students. Among other benefits, we found retention rates in small classes to be about 20% better than large classes.

Categories and Subject Descriptors
K.3.2 [**Computer and Information Science Education**]: *Computer Science Education*

General Terms
Human Factors.

Keywords
Introductory computer science, class size, active learning, assessment, underrepresented groups, pipeline.

1. INTRODUCTION
At North Carolina State University, introductory computer science (CS1) has traditionally been offered in large lecture sections of 150 or more students with separate lab sections of about 30 students each. Feedback from instructors and students has suggested that in large lecture sections, students – especially computer science (CS) majors -- may not be getting the quality of interaction they need. Like many other computer science departments across the country, over the last several years we have experienced not only a drop in the number of computer science majors, but also reduced retention of traditionally underrepresented groups [12, 14].

These concerns have prompted us to re-examine how we structure and teach CS1. The first step was to change the size of the class and integrate hands-on experience with the actual lectures. The second step would be to tune the content, such as in-class examples, to make it more attractive to freshmen by highlighting its relevance and impact in real life. However, we did not change the basic course content for this study.

In the Spring 2006 semester, we ran a pilot study with two small class sections featuring integrated lecture and lab sessions. There are two principal treatments in this study – class size and integration of lab work into the class. Both affect learning and interaction flows and have economic implications [2,3,8]. For simplicity, we will use the terms *large* and *small* classes to mean *large classes with separate lab sections* and *small classes with integrated lab sections* respectively.

Some of the research hypotheses are:

- Attitude: Students in small sections with integrated hands-on experience display a more positive attitude toward computer science than students in large sections.

- Underrepresented Groups: These improvements are noticeable for underrepresented groups specifically.

- Learning: Student learning, as reflected through exam scores, programming project scores and successful completion rates, are improved for students in small classes.

- Retention: Student retention in small sections is better than in large sections.

We present theories from cognitive psychology, educational psychology, and education which situate our study in its theoretical framework, as suggested in [6]. We also present results from related empirical studies which constitute a considerable body of evidence for the conclusions.

2. THE CLASS SIZE DEBATE
In universities in the United States, CS1 class sizes range from 10 to 25 students in small classes to huge course sections of several hundred students. While Bloom's foundational study [2] and later studies established the superiority of one-on-one tutoring, in most cases group instruction is the feasible alternative. This paper explores the hypothesis that a small class of roughly thirty students may be more beneficial for students than a larger class because valuable educational approaches like active learning become viable

[4]. On the other hand, there are studies that suggest student performance in subsequent classes is not adversely affected by large class size [11]. Some related work on closed versus open labs in CS1 has been done [9], where "closed labs" require students to attend a supervised laboratory class outside of lecture and "open labs" refers to not requiring any supervised laboratory time. Our study does not consider open labs, but instead considers traditional closed labs compared to integrating lab activities during actual class lecture time.

2.1 Active Learning

Many educational psychologists believe learners actively construct knowledge by fitting observations into existing mental schema and acquiring procedural knowledge through practice [3]. While *shallow learning* can be achieved by simple memorization of facts, *deep learning* cannot. Active learning approaches have been shown to encourage deep learning in students even with different learning styles [5] and have educational benefits over other traditional approaches [10]. In a large lecture class where students often sit passive and anonymous without even taking notes, the opportunity to interactively construct knowledge is lost. Even with great effort, active hands-on learning may be difficult to implement effectively in large classes.

2.2 Performance and Retention

There is empirical evidence that active learning enhances student performance in CS1 and increases student retention as reflected through lower dropout rates in CS2 [7]. A study of introductory economics classes found that although increasing class sizes held clear economic benefits, students in large classes were 38% less likely to re-enroll in later economics classes [8]. If smaller class sizes provide a higher quality student experience in CS1, such as a more personal environment and less guarded behavior [1], perhaps students will be more likely to return for future computer science courses.

3. DESIGN OF PILOT STUDY

For this semester-long study, we offered three large sections and two small sections of CS1. In the small classes, lab activities were integrated throughout the lecture. In large classes, students attended a separate lab session supervised by a teaching assistant.

3.1 Class Composition

Computer science majors were given preference for registration into small sections. Major and class size are not independent factors in this design, so we disaggregate the classes by major for much of our analysis. Table 1 provides a breakdown of the treatment groups by major. As we will see in the analysis section, the small number of computer science majors in large classes means some results which were statistically significant in general cease to be significant when we separate by major.

Tables 2 and 3 display the gender and racial makeup of the respondents from both treatment groups. As the tables illustrate, the number of students from underrepresented groups is small. Nonetheless, several statistically significant findings have emerged with respect to these groups.

Table 1: Respondent Major by Class Size

	Computer Science	Other Majors	
Large Classes	20 (11%)	166 (89%)	186
Small Classes	37 (73%)	14 (27%)	51
	57	180	237

Table 2: Respondent Gender by Class Size

	Females	Males	
Large Classes	20 (10%)	173 (90%)	193
Small Classes	4 (8%)	49 (92%)	53
	24	222	246

Table 3: Respondent Race by Class Size

	White	African American	Asian	Hisp-anic	Other	
Large Classes	148 (80%)	16 (9%)	15 (8%)	4 (2%)	3 (1%)	186
Small Classes	38 (74%)	6 (12%)	6 (12%)	1 (2%)	0 (0%)	51
	186	22	21	5	3	237

3.2 Instructors

There were four different instructors for the five course sections considered in this study. Along with accommodating the scheduling realities in our department, this arrangement may make our results more robust since there were two different instructors for small courses and two different instructors for large courses. In detailed instructor interviews, all instructors expressed similar views of their goals in the course: to give students a foundational understanding of programming and computing concepts, and to have them leave with the ability to solve basic programming problems. Instructors also use a set of common learning outcomes for the course.

Both small course instructors described an iterative process of presenting material: first presenting an abstract idea, then discussing a concrete example, then having students work on a concrete example on their computers. Both large section instructors described feeling somewhat detached from their students and having trouble keeping students engaged. They both reported standing at the front of the room most of the time and lecturing from projected material. Our classroom observations confirmed the instructors' accounts.

All instructors assigned the same programming projects, and analysis of programming project scores found no significant difference on any pair-wise test of means across the sections.

3.3 Data Sources

The empirical data in this study come from a variety of sources:

- **Surveys** – administered online. For small classes, the response rate was 86%, while for large classes the rate was 46%. This discrepancy is probably due to the fact that small sections had a higher attendance rate and students were supervised completing the surveys by their instructor. We received 237 complete responses. Respondents' gender, race, and SAT scores is representative of the distribution for all enrolled CS1 students at NC State.
- **Student Grades** – collected immediately after the end of the semester for all programming projects, tests, and the final examination. We discuss performance data from all 467 students who completed the course.
- **Standard Exam Questions** – placed into all midterm tests and final examinations.
- **Student Data** – including high school grade point averages, SAT scores, and grade point averages at our university. We collected demographic data including gender and ethnicity.
- **Instructor Interviews** – conducted to get an idea of each instructor's approach, teaching paradigm, and attitudes toward the classroom experience.

3.4 Survey Design

The sixty item student survey was designed by a committee of computing researchers, educators, and education researchers. Each survey item is a declarative statement to which students rate their agreement based on a five-value Likert scale. For our analysis, 4=strongly agree, 3=agree, 2=disagree, 1=strongly disagree, and 0=don't know. We treat "don't know" as missing.

4. STUDENT ATTITUDE

We used paired t-tests by student on each item of the pre- and post-survey to determine whether a statistically significant change in student attitude, reflected by categorical level of agreement, occurred over the semester. We also used Pearson's X^2 test for independence to determine whether the percent of students agreeing with each survey item on either the pre- or post-survey differed between treatment groups. All differences presented were found to be statistically significant with at least 97% confidence (α=0.03) unless otherwise noted.

Since large classes were mostly comprised of non-majors, and small classes were mostly comprised of majors (see Table 1), the difference between attitudes of majors and non-majors may be an additional explanatory factor along with class size. To mitigate this we performed separate analysis for large and small classes by major. Along with overall class size differences, we discuss the disaggregated results by major when they are relevant. We also performed separate analyses by gender and race. We consider underrepresented groups to include African-American, Native American, Hispanic, and all others besides White and Asian.

4.1 Class Environment

The evidence in this section suggests that students in small classes are more comfortable asking questions than students in large classes. We also find students in large classes less able to remain focused, stay on task, and follow the lesson as easily as students in small classes. Student responses to the following survey items indicate that students do not believe large lecture classes are best for their learning.

I feel that I can ask questions in class when I have a difficulty. At the beginning of the semester, students in large classes agreed at 3.0 that they could ask questions in class when they have a difficulty. But this agreement dropped to 2.8 at the end of the semester. In small classes, students strongly agreed with this statement throughout the semester at 3.7. As of the post-survey, 98% of students in small classes, but only 69% of students in large classes, felt they could ask questions in class when they had a difficulty. This sentiment was echoed in the instructor interviews, where one small class instructor said she fields multiple student questions during any class period, while in contrast a large class instructor said it is not uncommon for class periods to elapse without a single question from students. Disaggregated analysis by major returned a statistically significant drop in agreement for non-majors in large sections only.

I am able to remain focused, on task and follow the lesson. In small classes, 92% of students agreed that they can remain focused, on task and follow the lesson. This agreement remained steady throughout the semester. In large classes, average student agreement dropped from 2.9 to 2.7, with only 64% of students agreeing on the post-survey that they were able to remain focused, on task and follow the lesson. Disaggregated analysis by major returned a statistically significant drop only in agreement for non-majors in large sections.

Large lecture classes are best for my learning. Students in large classes showed an increased agreement with this statement over the semester: the average pre-survey response was 1.8, with a higher response of 2.0 for the post-survey. Students in small classes showed no change from the pre-survey response of 1.5. Both groups on average disagreed or strongly disagreed with the statement that large lecture classes are best for their learning.

4.2 Motivation toward Computer Science

Our data support the hypothesis that small classes with integrated labs are better than large classes for helping students see the relevance of computer science, and programming, to their lives.

I expect to have little use for computer science when I get out of school. Students who were in large classes see less use for computer science in their lives after they have taken the class! Over the semester, students in large classes showed a significant increase in agreement -- from 2.3 to 2.5 -- with the statement that they would have little use for computer science when they get out of school. Students in small classes maintained consistent average disagreement or strong disagreement at 1.6. Major is also an explanatory variable for this response. Disaggregated analysis by major shows a statistically significant difference for non-majors in large classes, but no change for majors in large classes. In small classes, neither majors nor non-majors changed attitude on this item.

4.3 Confidence

The results suggest that small classes contribute more to self-confidence in programming, especially for majors. We also found large classes may decrease a student's expectations of doing well in computer science, especially for non-majors.

I do not have a lot of self-confidence when it comes to programming. Students in large classes showed steady slight agreement with this statement (average 2.7). But students in small classes showed decreased agreement, from 2.0 at the beginning of the semester to 1.8 at the end of the semester. In other words, students in small classes experienced an increase in programming confidence during the semester, while students in large classes showed no change. Majors in small classes had increased confidence over the semester, while majors in large classes showed no change. Non-majors did not show a change in large or small classes.

I don't expect to get good grades in computer science. Students in large classes show increased agreement with this statement over the semester from 1.9 to 2.1. Students in small classes show no change at 1.5. Disaggregated analysis found that majors do not change in agreement despite class size, but non-majors in large classes display a decreased expectation of good grades.

4.4 Student Preferences on Class Type

Student responses indicate that most students prefer small classes, would rather have lecture and lab integrated than held separately, and find using a computer in class to be helpful rather than detrimental to their learning. In this section, all statistically significant differences resulted from hypothesis testing with at least 95% confidence (α=0.05).

Smaller classes with about 30 students in them are better for my learning. Majors, whether in small or large classes, agreed at 3.4 Non-majors in small classes agreed or strongly agreed at 3.7, but non-majors in large classes agreed at 3.1. Females agree more strongly than males, although for both genders the agreement strengthens in small sections. Females agree at 3.5 in large sections, and even more so in small sections at 3.75. Males agree at 3.0 in large sections and even more, at 3.4, in small sections. Students of underrepresented races may agree more strongly with this statement than students of other races. In large sections, underrepresented students agree at 3.4 more strongly than students of other races with at 3.1.

I prefer lecture and laboratory to be integrated together, so that I can practice what we learn in lectures at the same time. On average, all students agree or strongly agree with this statement. In small classes, both majors and non-majors strongly agree at 3.9, and in large classes both majors and non-majors agree but slightly less strongly at 3.4.

I prefer separate lectures with separate laboratory sessions to practice what we learned in lectures at my own pace. On average students disagree or strongly disagree with this statement. In large classes the response level is 2.0, while in small classes the average response of 1.4 leans even more toward strong disagreement. Analysis by race reveals there is not enough evidence to conclude that underrepresented groups have a preference either way on this item, but their average response is 2.1, expressing weak disagreement. Students from other races disagree or strongly disagree with average response 1.5.

Using a computer in class helps to keep me focused on the work. Students generally agree with this statement. In small classes, both majors and non-majors agree or strongly agree at 3.5. In large classes, both majors and non-majors agree at 3.0. Response to this item does not vary with gender or race.

If I have a laptop or computer in class I easily get distracted (e.g. send email messages, IM). Most students disagree with this statement. In large classes, majors disagree at 2.1 and non-majors also disagree at 2.3. In small classes, majors disagree at 2.0 and non-majors disagree more strongly at 1.75.

Testing out computer programming in class would benefit my learning. Students agree with this statement. Majors strongly agree at 3.6 in both small and large classes. Non-majors agree less strongly at 3.3 in both small and large classes. Males agree more strongly at 3.4 than females who responded 3.2 in large classes. In small classes, females agree more strongly at 3.75 than males who agreed at 3.4.

I prefer that the instructor personally knows who I am in class. Students agree weakly with this statement. In large classes, both majors and non-majors agree weakly at 2.8, but for majors in large classes this response is not statistically distinguishable from the neutral response of 2.5. In small classes all students agree at 3.1. Responses to this item do not vary by gender. There is no statistical significance to the variation by race, but in large classes students from underrepresented groups average 3.0 while students from other races average 2.7. The same holds for small classes, where underrepresented races average 3.25 while other students average 3.1.

5. LEARNING

To strengthen the case that the performance and retention differences discussed in this section stem from experimental factors and not prior attributes, all available data regarding student aptitude suggest no statistical difference between the aptitude of students in the treatment groups. Analysis of the available 212 SAT scores indicates that students in large and small sections have statistically equal SAT scores on both verbal and math portions. We also analyzed the available 231 prior grade point averages and found no statistical difference between treatment groups.

5.1 Standard Test Questions

Standard questions were designed by the CAC/ABET coordinator in the Department of Computer Science and inserted into each instructor's exam. Instructors did not have access to the standard question content prior to administering their examinations. Standard questions were graded by teaching assistants following a strict rubric. In the absence of double blind grading, we performed random sampling on the original final exams to verify the rubric was adhered to among graders. We found no evidence of inconsistency in the grading.

A two-sample t-test reveals that students in small classes scored better on standard exam questions than students in large classes. The average score on standard questions in small classes was 79%, but in large sections the average score was 62%. Results for these standard questions are not linked to individual students in the current data set, which made it infeasible to run separate analyses for majors and non-majors.

5.2 Successful Completion Rates

Our data suggest that both majors and non-majors have a higher success rate in small classes. For large sections, 83% of students who complete the class are categorized as passing. For small sections, a much higher 94% of students achieved success.

Perhaps the most interesting results come from disaggregated analysis by major. Non-majors in large classes have an 83% passing rate, while non-majors in small classes have a higher 86% passing rate. Majors in large classes achieved a passing score 90% of the time, while majors in small classes passed 97% of the time.

6. RETENTION

We define retention as the percentage of students originally enrolled in the course who remain enrolled throughout the semester. Our analysis indicates the student retention rates are strikingly different between class sizes. The two small sections have retention rates of 87% and 97%. The three large sections experienced retention rates ranging from 66% to 75%.

As our study continues, we will collect long-term persistence data for this group of students. As of one semester after this initial study, 87% of computer science majors from small classes were enrolled and still majoring computer science. For large classes, this number is significantly lower at 75%. For underrepresented groups, 100% of small class computer science majors had persisted in the major after one semester, while 83% of large class computer science majors remained.

7. CONCLUSION AND FUTURE WORK

This study indicates that small classes with integrated labs hold many benefits for students over large classes with separate labs. Our data show the following outcomes with regard to our research hypotheses:

- Attitude: Students in small sections show a more positive attitude, such as feeling more able to ask questions, and having less difficulty staying focused and keeping on task than students in large sections.
- Underrepresented Groups: The benefits observed from smaller classes were apparent, and often magnified, for students in underrepresented groups.
- Learning: Performance on standard test questions shows better learning for students in small classes, and students in small classes have a higher successful completion rate despite comparable aptitude and GPA in pre-analysis.
- Retention: Retention rates across the semester were approximately 20% higher in small sections.

This study will be repeated in the Fall 2006 and Spring 2007 semesters using similar experimental conditions, but with more extensive classroom observation and modifications to the survey which will give insights into a student's learning tendencies before and after the class. We will also investigate reasons for student choice of large or small sections, since we have allowed more freedom for majors and nonmajors in selecting sections.

In the midst of debates over curriculum issues, programming paradigms, concept inventories, and other crucial endeavors in computer science education research, educators are awash in a sea of choices. Practitioners and policymakers in computer science education seek to act in the best interest of our students – but the choice of pedagogical approaches has competing, contradictory aspects. The evidence presented in this paper supports the notion that students can be better served by small class sizes enhanced with active learning approaches.

8. ACKNOWLEDGEMENTS

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