The Exploring Computer Science Course, Attendance and Math Achievement

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ABSTRACT
Exploring Computer Science (ECS) is a high school curriculum that was designed to be more inclusive and engaging for all students, especially women and students of color who have typically been under-represented in the discipline. The course uses an inquiry-based approach that is expected to improve students’ problem solving skills. Students who enrolled in ECS at ten high schools in San Jose, California were monitored over a three-year period to investigate possible relationships between participation in ECS, attendance rates, and scores on standardized math tests. Results show a statistically significant difference between ECS participants and their peers in both areas for two of three project years. Additional study is recommended to explore whether there is a causal relationship.

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

General Terms
Measurement, Achievement, Performance, Experimentation.

Keywords
Pre-college, high school, pre-AP, curricula, math, attendance.

1. INTRODUCTION
In 2010, the authors began an NSF project to establish Exploring Computer Science (ECS) at ten suburban public high schools from three school districts in the greater San Jose, California area. ECS is a pre-Advanced Placement (AP) course providing an introduction to the breadth of computer science. Assignments and instruction are inquiry and equity based and designed to be socially relevant and meaningful for diverse students.

1.1 ECS and Problem Solving
ECS develops problem solving skills throughout the six units of the curriculum. Unit 1 (Human Computer Interaction) establishes a problem-solving foundation by showing how “intelligent” machine behavior is simply algorithms applied to useful representations of information and by exploring what makes certain tasks easy or difficult for humans. Unit 2 (Problem Solving) develops the basic steps of problem-solving, including the problem statement, algorithm design, implementation, testing, and verification. The unit also explores selected topics in discrete mathematics such as Boolean logic, functions, sets, graphs, and the binary number system. Exercises are presented that illustrate the value of abstraction in solving programming problems. Unit 3 (Web Design) reinforces abstraction through the hierarchical and structured design of Web pages using HTML and CSS. In Unit 4 (Programming), students develop algorithms and programming solutions to a variety of problems using Scratch and see the benefits and limitations of different data structures when used as a fundamental organizing principle in the design of solutions. Unit 5 (Computing and Data Analysis) explores the use of computers to translate, process and visualize data in order to find patterns and test hypotheses. Much of this is put in practice in Unit 6 (Robotics) to build and program a robot to solve a required task.

1.2 ECS Teachers
The Santa Clara County Office of Education requires computer science to be taught by math-certified teachers. Participating schools were therefore selected by their respective district office based on the interest and availability of math teachers in their schools who were not needed to teach math courses. Five teachers participated in a four-week professional development workshop during the summer of 2010. Of those, three began to teach ECS in 2010-11, one began in 2011-12, and one was reassigned to a different course just before school began. Seven additional teachers received training in the summer of 2011. Six of those began teaching ECS in 2011-12 and one was reassigned. Ultimately, ECS was offered at each of ten high schools by the fall of 2011.
Only four of the teachers had previously taught a computer science course; one of those had previously worked in industry as a software engineer. All received stipends for attending the training. A second NSF grant provided teachers with academic-year stipends and computer science graduate students as in-class teaching assistants for three years starting in the fall of 2011.

1.3 ECS Students
Over the course of the project, 755 ECS students from grades 9 through 12 were monitored to compare their attendance rate to the overall average by school. In addition, scores on the math portions of the California STAR Test (CST) taken by 532 ECS students in grades 9 through 11 were compared to scores of non-ECS students attending the same schools. (12th graders don’t take CST exams.) All students self-selected to enroll in ECS since it was offered only as an elective. Demographics varied from one school to another. In total, however, 20% of the ECS students were female, 58% Asian, 22% Caucasian, 12% Hispanic, and 3.6% African American.

1.4 ECS and Curriculum Standards
SRI International received an NSF grant to develop mappings of the unit objectives and computational practices of the ECS curriculum to several state and national standards [11]. SRI hired an experienced ECS teacher with a credential in mathematics to develop the initial mappings, and then had the mappings reviewed by external experts, including other ECS teachers and computer science content specialists.

ECS was mapped to many of the mathematical practice objectives in the Common Core State Standards (CCSS): making sense of problems and persevering in solving them, abstract and quantitative reasoning, constructing viable arguments and critiquing the reasoning of others, mathematical modeling, and the strategic use of appropriate tools. ECS was also mapped to several mathematical content objectives: creating equations, building functions, understanding independence and conditional probability, making references and justifying conclusions, and interpreting categorical and quantitative data.

The mappings simply reflect personal judgments informed by years of experience, but serve to recognize the relationship between ECS and mathematics that motivates this study.

The CCSS were not available at the time the ECS course was offered during this study. Although the data presented here does not reflect the results of content tests that were specifically designed to assess CCSS, the mapping done suggests that ECS participation may have further beneficial impacts for students taking a math curriculum founded on the CCSS mathematical practice objectives.

2. RELATED RESEARCH
In the Los Angeles Unified School District, where it was originally created, females, African Americans and Latinos who had taken ECS exhibited significantly higher AP CS participation rates than the national and California averages [9].

Tracy et al [7] have recommended problem solving as a fundamental and important skill needed in mathematics and other subjects:

> Instructional programs from prekindergarten through grade 12 should enable all students to build new mathematical knowledge through problem solving; solve problems that arise in mathematics and in other contexts; apply and adapt a variety of appropriate strategies to solve problems.

Their data supports evidence of a relationship between inquiry-based strategies used in the classroom and students’ math problem-solving.

Other early studies investigated the effects of computer programming in LOGO on student achievement in mathematics. Milner [3] suggested that 5th grade students could learn the concept of a variable through programming and that it helped them to develop problem-solving skills. Noss [4] found that LOGO programming improved elementary school students’ understanding of the geometric concepts of angle and length, especially for girls. Clements and Battista [1] studied 3rd grade children and reaffirmed that LOGO had a positive effect on their geometric conceptualizations, but also that their responses during discussions were more mathematically coherent and abstract.

More recently, the programming environment Bootstrap has been used to teach middle school students about algebra and coordinate geometry by having them develop their own video games. Schanzer et al [6] and Wright [8] found that Bootstrap provided statistically significant improvements on standard algebra word problems and function composition problems, and extensive anecdotal evidence that Bootstrap builds student confidence in mathematics.

An unpublished investigation, “Computer Science Course May Improve Math Scores,” (February 2013) [Pirmann, personal communication] found that high school students who took computer science performed better on the Pennsylvania System of School Assessment (PSSA) math test. Before implementing computer science, between 76% (2006) and 79% (2007) of students were scored above “Below Basic” on the PSSA. After implementing computer science (as a module of other technology courses, or as a full course), the percent of students scoring in this same range increased to between 83% (2008 and 2009) and 90% (2012).

3. METHODS
Independent sample t-tests were applied to attendance data to compare the mean percent attendance of students in ECS classes to non-ECS students in all participating schools. To compare math CST scores across ECS and non-ECS students, a simple random sample of non-ECS students was taken to match the size of the ECS group (n=539). The math CST data was analyzed using a series of independent sample t-tests, comparing ECS participants to non-ECS students disaggregated by each of the following variables:

- Year of participation
- Math CST test
- School
- Grade level
- Gender

In addition, a factorial ANOVA was conducted that compared ECS participation for students based on the combination of their grade level and the math CST test they took. Finally, a multiple linear regression was conducted to control for the confounding variable of course acceleration (whether a student is in a standard course for her grade level or a higher-level course). Students were classified according to when they took their math CST test:

**Accelerated:**
- Alg II – 9th Grade
- Summ. Math – 9th, 10th Grade

**Non-Accelerated:**
- Alg I – All Grades
- Geom – All Grades
- Alg II – 10th, 11th Grade
- Summ. Math – 11th Grade
For all tests, means, standard deviations, and p-values are presented. In general, in accordance with social science convention, any p-value of .05 or less is considered statistically significant and is marked with an asterisk (*) in the graphs and tables.

4. ATTENDANCE

The possibility of a direct relationship between attendance rate and increased math achievement was not investigated in this study. However, higher attendance rates were expected to increase overall academic performance, and thus we were interested to learn if ECS students had higher attendance rates than non-ECS students.

Table 1 shows the ECS student attendance by school compared to the overall attendance rate of the high school for the 2010-11, 2011-12, and 2012-13 school years. Empty cells correspond to years in which a particular school did not offer ECS. Results vary considerably depending on the school; however, the overall trend is that students enrolled in ECS had higher attendance rates compared to students not enrolled in ECS.

In each of the three years that ECS was offered at these schools, the mean ECS student attendance rate was higher than the mean overall attendance rate across schools. The gap between the mean ECS attendance rate and the mean overall attendance rates increased each year. Boldface and shading are used to highlight entries in the table where ECS students’ attendance rates exceed the corresponding school average by five percentage points or more. In 2011-12 and 2012-13 the mean attendance rate for ECS classes across all schools was significantly higher than for the schools as a whole.

<table>
<thead>
<tr>
<th>School</th>
<th>2010-11 Overall Attendance</th>
<th>2010-11 ECS Attendance</th>
<th>2011-12 Overall Attendance</th>
<th>2011-12 ECS Attendance</th>
<th>2012-13 Overall Attendance</th>
<th>2012-13 ECS Attendance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evergreen Valley</td>
<td>97.2% 98.3%</td>
<td>99.6% 98.7%</td>
<td>98.0% 98.1%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Independence</td>
<td>- -</td>
<td>95.2% 98.2%</td>
<td>97.2% 97.2%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oak Grove</td>
<td>94.2% 95.5%</td>
<td>93.4% 99.0%</td>
<td>95.0% 100.0%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pioneer</td>
<td>96.2% 95.1%</td>
<td>95.5% 96.1%</td>
<td>96.2% 97.3%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>San Jose High</td>
<td>- -</td>
<td>93.8% 96.7%</td>
<td>95.5% 96.6%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Santa Clara</td>
<td>- -</td>
<td>98.3% 96.4%</td>
<td>95.3% 96.7%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Santa Teresa</td>
<td>- -</td>
<td>98.7% 98.5%</td>
<td>95.8% 96.9%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silver Creek</td>
<td>- -</td>
<td>95.1% 98.3%</td>
<td>- -</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adrian Wilcox</td>
<td>- -</td>
<td>96.4% 98.4%</td>
<td>91.7% 96.3%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Willow Glen</td>
<td>- -</td>
<td>95.8% 96.5%</td>
<td>96.7% 97.2%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>95.87% 96.30%</td>
<td>96.18% 97.68%</td>
<td>95.71% 97.37%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difference in attendance rates</td>
<td>+0.43 percentage points</td>
<td>+1.5 percentage points</td>
<td>+1.66 percentage points</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>p-value</td>
<td>p = .38</td>
<td>p &lt; .03*</td>
<td>p &lt; .02*</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. MATH ACHIEVEMENT

Math CST scores of ECS and non-ECS students in 2010-11, 2011-12, and 2012-13 were compared to assess whether there is a relationship between participation in ECS and achievement in math.

Students were not tracked from year to year, and therefore the evaluators were not able to distinguish between students who had never taken ECS and those who had taken it prior to a particular project year. The most likely impact of this is that a relatively small number of former ECS students were counted as non-ECS students in subsequent years, potentially causing the relationship between ECS and math achievement to appear smaller than it actually is. Data for one school in 2010-11 was removed due to a small ECS sample size (n=6) and because the teacher only taught half of the ECS curriculum.

5.1 Overall Scores

When aggregated across all three years, of the 1071 students, those who were enrolled in ECS had scores that were significantly higher than non-ECS students (t = 6.2, p < .01). Overall, ECS students’ mean CST score was 359 (s.d. = 84.4), while non-ECS students’ mean score was 330 (s.d. = 68.2). When each year of the program was considered on its own, the same statistically significant difference was found for 2011-12 (p < .01) and 2012-13 students (p < .01). No significant difference was found for 2010-11 (p = .20) students, but this is not surprising considering the small sample size for that year (only two sections of ECS were included in the analysis). Overall, the data demonstrate an increasing difference over time between mean CST score for ECS and non-ECS students across the program. Figure 1 shows that scores were lower in 2010-11, and 29 and 40- points higher for ECS students than the comparison group for the following two years respectively (standard deviations are in parentheses).
5.2 Scores by Grade Level

Differences in CST scores were also assessed by categorizing data by students’ grade level to determine whether a relationship exists with ECS participation. The analysis demonstrated that across all project years ECS students had higher CST scores at each grade level (9, 10, and 11) compared to non-ECS students. Overall, there appears to be a correlation between participation in ECS and students’ CST scores regardless of their grade level. The difference in CST score was largest for 9th graders (42 points, \( p < .01 \)) and smallest for 11th graders (13 points, \( p < .10 \)), with 10th graders in the middle (29 points, \( p < .01 \)), as shown in Figure 2 (standard deviations are in parentheses).

5.3 Scores by CST Math Test

Differences in CST scores were additionally assessed by categorizing CST data by math subject to assess whether a relationship exists between participation in ECS and understanding of various math subjects. As shown in Figure 3, ECS students who took the Algebra II (\( p < .01 \)), or Summative Math (\( p < .05 \)) CST scored significantly higher than non-ECS students. With the highest mean difference, students in ECS who took the Algebra II test scored 49 points higher than non-ECS students. The differences for Geometry and Algebra I were not statistically significant; Geometry ECS students scored 8 points higher than the comparison group (\( p = .23 \)), while Algebra I ECS students had a mean score 10 points lower than the comparison group across all project years (\( p = .23 \)).
5.4 Scores by Math Placement
California's content standards recommend that students take Algebra I in 8th grade, Geometry in 9th, Algebra II in 10th, and the Summative Math test in 11th grade [11]. Table 2 categorizes CST math scores by test subject and student grade level when taken, thus allowing students to be grouped relative to this recommendation and (by implication) their affinity for math.

Students following the recommended sequence are highlighted in the table and represent 45% of ECS and 33% of non-ECS students. Students in the lower right of the table are following an accelerated math sequence and comprise 18% of ECS and 7% of non-ECS students. However, many of the state's students do not begin Algebra I until 9th grade or later. They are those in the upper left, and represent 37% of ECS and 60% of non-ECS students.

The data shown in a light italic font for 10th and 11th grade Algebra I and for 9th grade Summative Math is inconclusive due to very small samples sizes of ECS students, invalidating any meaningful comparisons in those subgroups.

Students who do well in math typically also do well in computer science. Since students self-select ECS as an elective, one might suspect that ECS students are mostly those that excel in math. Indeed, the table indicates that fewer ECS students began Algebra I late and more of them follow an accelerated math sequence compared to their peers.

ECS students who had higher CST math scores than non-ECS students tend toward the lower right of the table, indicating that the strongest relationship was observed for accelerated math students who participated in ECS early in their high school career.
The table also shows, however, that other ECS students also experience gains.

Multiple linear regression results demonstrate that when controlling for students’ relative placement in math courses (e.g. standard vs. accelerated), ECS participation is associated with increased student’s math CST score by 18 points ($p < .01$).

5.5 Scores by Gender
Differences in CST scores were also assessed by categorizing data by gender to assess whether participation in ECS influences males and females differently. Across all project years, male ECS students’ mean CST score was 362 (s.d.=85.3) while males in the comparison group scored 330 (s.d.=70.2) on average. On average, female ECS students scored an average of 347 (s.d.=80.3) and non-ECS females scored 330 (s.d.=66.2). Both differences were statistically significant ($p < .01$ for males and $p < .03$ for females). No significant difference in CST scores for males vs. females related to participation in ECS was evident ($p = .13$).

6. SUMMARY
Overall, the data indicates an encouraging correlation between ECS participation, attendance rates and academic achievement as measured by performance on the CST math test:

- **Attendance:** In the last year of the study, ECS students’ attendance was higher than overall attendance for eight out of nine schools, which may have indirectly contributed to an increase in ECS students’ CST math scores.

- **CST Math Overall:** ECS students at all schools had higher CST math scores than non-ECS students across all years of the study. These differences were statistically significant in five of the ten schools, and approached significance in four.

- **CST Math by Grade Level:** ECS students had statistically significantly higher CST scores at each grade level, with 9th graders having the greatest difference.

- **CST Math by Gender:** Observed differences in CST math scores do not appear to differ significantly by gender.

- **CST Math by Subject:** ECS student scores were statistically significantly higher in Algebra II and Summative Math and approached significance in Geometry. No difference in Algebra I scores was observed, but this result is inconclusive due to the small number of ECS students in the sample.

- **CST Math by Placement:** The strongest correlation seems to exist between accelerated math students who participated in ECS early in their high school career.

The large number of factors affecting the data makes it impossible to claim causation, yet we believe that our results do confirm a synergistic effect between computer science and mathematics as described by Rich et al [5]. Further research should attempt to collect pre- and post-test data from experimental and comparison groups to assess whether baseline abilities of experimental and comparison groups are statistically significantly different. In addition, tracking students over time to compare students who have never taken ECS to those who are taking a course would be beneficial. Finally, since the number of students in ECS was relatively low compared to non-ECS students, increasing the size of the ECS group will also improve the power of the analyses conducted by correcting for unmet statistical assumptions.

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8. REFERENCES