An Examination of Factors Correlating with Course Failure in a High School Computer Science Course

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Abstract

Across the United States, enrollment in high school computer science (CS) courses is increasing. These increases, however, are not spread evenly across race and gender. CS remains largely an elective class, and fewer than three-fourths of the states allow it to count towards graduation. The Chicago Public Schools has sought to ensure access for all students by recently enacting computer science as a high school graduation requirement. The primary class that fulfills the graduation requirement is *Exploring Computer Science* (ECS), a high school introductory course and professional development program designed to foster deep engagement through equitable inquiry around CS concepts. The number of students taking CS in the district increased significantly and these increases are distributed equitably across demographic characteristics. With ECS serving as a core class, it becomes critical to ensure success for all students independent of demographic characteristics, as success in the course directly affects a student's ability to graduate from high school. In this paper, we examine the factors that correlate with student failure in the course. At the student level, attendance and prior general academic performance correlate with passing the class. After controlling for student characteristics, whether or not teachers participated in the professional development program associated with ECS correlates with student success in passing the course. These results provide evidence for the importance of engaging teachers in professional development, in conjunction with requiring a course specifically designed to provide an equitable computer science experience, in order to broaden participation in computing.

Keywords: high school computer science, Exploring Computer Science, computer science teaching practices, graduation requirement, broadening participation

1 Introduction

In recent years, an increasing number of schools in the United States have been planning or implementing new computer science (CS) offerings, with a significant surge after President Obama's announcement of the Computer Science for All Initiative in 2016. In most districts, however, computer science courses remain an elective, and only three-fourths of the states allow them to count towards graduation [3]. While increased access has had some positive effects on broadening participation, enrollment has not spread evenly across race and gender. In contrast, Chicago Public Schools (CPS) has sought to reach all students by enacting

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a year-long computer science course as a high school graduation requirement. CPS includes close to 175 high schools (97 of which are district-run) serving approximately 110,000 students. 47% of the student population is Hispanic, with 37% being African-American and 10% white. The primary course that fulfills the graduation requirement is *Exploring Computer Science* (ECS) [7], an introductory computer science course designed to foster deep engagement through equitable inquiry around CS concepts. The course was initially developed for the Los Angeles Unified School District and is now being taught in 25 U.S. states and Puerto Rico, reaching approximately 50,000 students annually [6]. In CPS, ECS is currently being taught in 74 high schools to 11,000 students by over 130 teachers. The demographics of students taking ECS since the enactment of the graduation requirement closely match the demographic characteristics of the district and represent significant progress towards the goal of achieving "CS for All."

Achieving a district-wide implementation creates the need to develop a large cadre of CS teachers with the appropriate training to faithfully implement the curriculum and be true to all three strands at the core of ECS: equity, inquiry and CS concepts.

The course is paired with an extensive professional development (PD) program [8] consisting of a one-week summer institute prior to implementation of the course, four day-long workshops during the academic year, and a culminating week-long summer institute the summer after first implementing the course. Independent of a teacher's CS prior knowledge, effective teacher learning requires multiple PD experiences over an extended period of time to allow for reinforcing concepts, practice, and reflection. In addition, being able to teach the course multiple times helps teachers hone the equitable teaching practices learned during professional development.

The scale of the implementation in CPS revealed inconsistencies in the fidelity to the professional development model. Teachers who are not certified to teach computer science are expected to complete the ECS professional development program to be considered qualified to teach the ECS course. However, there are currently no no accountability measures for teachers not certified in computer science who do not attend the PD and who teach the ECS course. At times this can occur when teachers are hired just before the school year starts and it is too late in the summer to attend ECS PD. For teachers who are certified to teach computer science, the ECS PD is highly recommended but not required.

Prior studies related to ECS have successfully documented the impact of professional development on ECS implementation and have showed positive student outcomes in ECS courses related to attitudes towards computer science, choices about future CS coursework, and development of computational thinking practices [8, 5, 14, 15].

With ECS becoming a high school graduation requirement it is critical for the district to ensure success in the course for all students independent of demographic characteristics, since failure in the class will affect a student's ability to graduate. Failure in any one class may significantly increase the likelihood of a student dropping out altogether [1]; currently, the most significant catalyst for dropouts is failure in Algebra I [16].

This paper examines student- and teacher-related factors that have the potential to impact students' failure in the ECS course. Student factors include prior cumulative grade point average and demographic characteristics. Teacher-related factors include prior experience with teaching ECS and participation in the ECS professional development program. We hypothesized that students failing ECS are likely to be failing other courses as well, and students are more likely to perform well when their teachers have completed the ECS PD.

2   The ECS Curriculum

The Exploring Computer Science (ECS) curriculum and professional development program was crafted at the University of California, Los Angeles and at the University of Oregon, with the goal of contributing to broadened participation of women and minorities and increased equity in the field of computer science [13].

The ECS curriculum is composed of activities that are designed to engage students of diverse backgrounds in computer science inquiry around meaningful problems.

When computer science is not taught for deep engagement but rather as an abstract academic subject, it privileges access to mostly Caucasian, male students [11]. To play an integral role in such classrooms, students must master abstract programming for programming's sake.

In contrast, the ECS curriculum is designed to engender deep engagement with important computer science concepts by mimicking important features of communities in which youths participate outside the classroom. General technology use outside of school by youths of all races and genders tends to revolve around making social connections and working on practical problems [10]. Reorienting computer science instruction to be culturally relevant and focused on problem-solving experiences that are meaningful to students has the potential to increase access to computer science content, provide students with integral roles, and create opportunities for students to express themselves [2]. At the college level, computer scientists at Carnegie Mellon University increased representation of women in their computer science program by making such changes to the nature of instruction in their introductory courses. Students develop technical fluency through solving problems of interest [12].

At the core of ECS are a set of high-leverage teaching practices [9] that support the three interwoven teaching strands of ECS: equity, inquiry, and CS concepts. The following high-leverage teaching practices enable students to equitably participate in student-led inquiry around important CS concepts: (a) provide a meaningful context for learning; (b) scaffold the development of CS concepts; (c) facilitate peer inquiry and collaboration; and (d) encourage multiple forms of expression [7, pp. 7–8]. Inclusiveness is supported by focusing on ideas that are meaningful to students, and activities in the curriculum provide space for teachers to incorporate students' background and culture. In addition, many activities focus on real-life issues in the community; for example, students can make games that communicate messages about healthy eating or about the plight of undocumented students [13]. Resting on equity are inquiry-based activities in which students are "expected and encouraged to help define the initial conditions of problems, utilize their prior knowledge, work collaboratively, make claims using their own words, and develop multiple representations of particular solutions." [13] By engaging students in equitable inquiry through the first two strands, students gain access to the domain content of computer science, the third strand.

3   ECS Professional Development

Curriculum materials and activities represent one component of the ECS program. Given the significant shift in the nature of computer science teaching required for successful implementation of ECS, teachers need extended professional development to successfully adapt to the ECS model of teaching [8]. The ECS PD program is intentionally designed to prepare teachers to implement the inquiry-based activities while also guiding them to build a classroom culture that is inclusive of all students [8]. Professional development begins with a weeklong summer workshop prior to implementing ECS. There are five key components of the ECS professional development model, the first being that teachers engage in the process of collaborative inquiry in small groups in the same way that students will engage in inquiry. The second component is that, throughout the first week, teachers participate in inquiry specifically through a teacher-learner-observer model. Each small group is assigned a lesson in which the group co-plans and teaches the lesson to the rest of the participants, who experience the lesson as learners. After the lesson, all the participants engage in reflective discussion about the experience from the point of view of the three ECS teaching strands (equity, inquiry, and CS content). These first two components of ECS professional development are consistent with what Desimone and Garet [4] call active learning in professional development. Their review of professional development found that active learning was an important component of professional development as it significantly influenced changes in teacher practices.

The third component of ECS professional development is explicit discussion and reflection on equitable

Table 1: Number of ECS teachers and students by school year

School Year	Teachers	Students
2011–12	10	385
2012–13	28	1970
2013–14	51	3141
2014–15	69	4559
2015–16	75	4503
2016–17	118	7801
Total	176	22,359

practices. During the workshop, the teachers read sections of Stuck in the Shallow End [11], which provides rich case study descriptions of the roots of inequity in computer science. The fourth and fifth components of ECS PD are meant to sustain teacher development over long time spans, which is another key dimension of effective PD [4]. The fourth component is ongoing professional development during the school year and a second weeklong workshop the summer after their first year of implementation. The fifth component of ECS PD is the development of a professional learning community. It begins in the summer workshop through the formation of small groups that engage in collaborative inquiry. It is also built up through the trust that teachers develop as they engage in tough, open discussions about equity as well as through open, honest feedback on lesson design and implementation during the workshops.

4   Methods

CPS has been implementing the ECS curriculum and professional development program since the 2011–12 school year. This study covers the six years from the 2011–12 to the 2016–17 school years. Table 1 shows the number of teachers who taught an ECS course and the number of students who completed an ECS course each school year. There has been a total of 176 teachers who have taught ECS at least once during the study period; since teachers may have taught ECS in more than one school year, the number of teachers by year sums to more than 176. There were more than 22,000 students who have completed an ECS course during the study period. There was steady growth in the number of teachers teaching and students completing ECS from 2011–12 to 2015–16 school years. During that time period, ECS was offered as an elective course. The 2016–17 school year was the first year of the new graduation requirement; the students who entered high school during that year are the first to whom the graduation requirement applies.

Table 2 shows the distribution of the total number of times a teacher taught ECS during the study period. Almost three-fourths of the teachers taught ECS 1–2 times during that time. About one in seven of the teachers taught ECS 4 or more times. Of the 176 teachers who taught ECS at least once during the study period, roughly two-thirds ($n = 119$) participated in the ECS professional development program and roughly one-third ($n = 57$) did not participate in any of the PD program.

As indicated above, there were 22,359 students who completed the ECS course during the study period. The rate of failing at least one semester for these students was 10.6%. Students from whom we were missing demographic information were dropped from the analyses, leaving a total of 17,514 students who were included in the analyses. The rate of failing at least one semester for the subgroup of students from whom we have complete demographic data is 11%, whereas the rate for students with missing demographic data was slightly lower at 9%.

Table 3 shows the summary of the demographic and performance data for the population of students from whom we have complete demographic data in comparison to the total population of high school students

Table 2: Distribution of the total number of times a teacher taught ECS

Number of Times	ECS Teachers
1	49%
2	23%
3	14%
4 or more	14%

Table 3: Demographic characteristics of ECS students relative to the general district population

Demographic Information	ECS Students	District Students
%Female	44%	—
%Caucasian	9%	8%
%African-American	37%	43%
%Hispanic	47%	43%
%Asian	5%	3%
%Free or reduced lunch	87%	85%
%Special education	15%	15%
%English language learner	8%	6%
%Freshman	59%	25%
%Sophomore	24%	27%
%Junior	6%	25%
%Senior	11%	22%
Attendance rate	89%	87%
Failure rate	11%	—
Cummulative GPA	2.5	—

in the district. Although there was a significant percentage of females taking an ECS class, there still were fewer females than males. The racial/ethnic characteristics of the ECS students were mostly reflective of the district population as a whole. There were slightly more Hispanic students and slightly fewer African American students in ECS classes than in the general population. The percentages of special education, free and reduced lunch, and ELL students were consistent with the district percentages. The majority of students taking ECS were freshmen, which is consistent with the year that the district recommends that schools offer the course to students. The overall attendance rate for ECS students was slightly higher than for the district as a whole. The average cumulative GPA during the year in which students took ECS was roughly a C+.

Since students were nested within classes and classes were nested within teachers across multiple years, we conducted hierarchical linear modeling on the probability of failure using WHLM software version 7.24q. Since the failure rate is a dichotomous variable, we used logistic regression. In the equation below, η_{ijk} represents a logit score, which is the log of the odds that a student will fail the ECS class. Taking the exponential of the logit gives the odds, or the probability of failing the course divided by the probability of passing the course; thus, the probability of failure can be calculated by dividing the odds by 1 plus the odds. Positive coefficients (γ values) indicate that the corresponding variable increases the probability that students will fail the course, and negative coefficients indicate that the variable decreases the probability

that students will fail the course.

$$
\begin{aligned}
\eta_{ijk} = \; & \gamma_{000} + \gamma_{001} * ECS\_PD_k + \gamma_{010} * PRIOR\_ECS\_EXP_{jk} + \gamma_{100} * ATTENDANCE_{ijk} \\
+ \; & \gamma_{200} * CUM\_GPA_{ijk} + \gamma_{300} * IS\_FRESHMAN_{ijk} + \gamma_{400} * FEMALE_{ijk} \\
+ \; & \gamma_{500} * AFRICAN\_AMERICAN_{jk} + \gamma_{600} * HISPANIC_{ijk} \\
+ \; & \gamma_{700} * SPEC\_ED_{ijk} + \gamma_{800} * IS\_FRL_{ijk} + \gamma_{900} * IS\_ELL_{ijk} + r_{0jk} + u_{00}
\end{aligned}
$$

There were three levels to the HLM model. At the first level were the student characteristics, which included the annual attendance rate, the cumulative GPA in the year in which the student completed ECS, whether the student was a freshman, female, African American or Hispanic (versus other races), in special education, participated in free or reduced lunch program (FRL), or participated in the English language learning program (ELL). All of these factors were fixed effects. Attendance and cumulative GPA were group mean centered.

Since the teachers could teach ECS across multiple years, level two represents the courses. The only variable at level two is the number of times that a teacher had taught ECS prior to a given school year. $PRIOR\_ECS\_EXP$ was treated as a fixed effect in the equation listed above. The random effect for the level-two intercept was represented as r_{0jk}. The third level of the HLM represented the teachers. The only level-three variable was an indicator variable signifying whether a teacher attended the ECS PD. The random effect for the level-three intercept was represented as u_{00} in the equation above. After controlling for student characteristics, the HLM analyses provide evidence on the extent to which engagement in the professional development and experience implementing ECS correlated with lower failure rates.

5   Results

As indicated above, the overall rate of failing either the first or second semester of ECS is 11% for the study group. We first examined whether there was a difference in the failure rate by semester. Table 4 shows a crosstab of the distribution of pass/fail by semester. There were almost 2500 students who, for a variety of reasons, were only enrolled in one semester, so they were dropped from this semester analysis. In the remaining population, 90% of the students passed both semesters, which is consistent with the study population average of 89%. Based on a chi-square test of independence, there was a statistically significant difference in the failure rate by semester ($\chi^2(1, 15,035) = 3864.5$, $p < 0.001$). The overall failure rate in the first semester was 5% and in the second semester, it was 8%. This differential in failure rate by semester may reflect an increased level of difficulty for both the teachers and the students in the later units in ECS.

Table 4: Distribution of the failure rate by semester

	Spring Pass	Spring Fail	Total
Fall Pass	13540	739	14279
Fall Fail	230	526	756
Total	13770	1265	15035

In order to investigate the student and teacher characteristics that correlate with the failure rate, subsequent analyses used the combined rate of failure indicating that the student failed at least one semester for the study population. Table 5 shows the results of the three-level HLM analyses of student, course, and teacher characteristics that correlate with the probability of student failure in ECS. The coefficients represent logit values, which is the log of the odds of failing the class. Positive logit values increase the probability

Table 5: HLM Model results for probability of failure in ECS, by student, course, and teacher characteristics.

Characteristic	Coefficient	Standard Error	t-ratio	p-value
Average	**−3.43**	**0.29**	$t(167)=-11.50$	$p <0.001$
Student Characteristics				
Cummulative GPA	**−2.44**	**0.07**	$t(17,037)=-35.07$	$p <0.001$
Rate of Attendance	**−4.46**	**0.31**	$t(17,037)=-14.52$	$p <0.001$
Freshman	**−0.41**	**0.11**	$t(17,037)= -3.76$	$p <0.001$
Female	**−0.30**	**0.08**	$t(17,037)= -3.88$	$p <0.001$
Hispanic	**0.28**	**0.13**	$t(17,037)= 2.18$	$p =0.029$
African-American	0.15	0.15	$t(17,037)= 0.98$	$p = 0.329$
Special Education	**0.26**	**0.09**	$t(17,037)= 2.89$	$p =0.004$
Free and Reduced Lunch	0.10	0.13	$t(17,037)= 0.78$	$p = 0.434$
ELL	**0.28**	**0.12**	$t(17,037)= -2.32$	$p =0.020$
Course Characteristics				
Years of Prior ECS Teaching	**−0.18**	**0.09**	$t(129)= -2.01$	$p =0.046$
Teacher Characteristics				
Attended PD	**−0.79**	**0.29**	$t(167)= -2.74$	$p =0.007$

of failure and negative logit values decrease the probability of failure. The factors in bold are statistically significant.

There are a variety of student characteristics that are statistically significant. Female students are less likely than male students to fail. Hispanic students are more likely to fail ECS relative to students who identify with other races. Correspondingly, students in an English language learner program (which in CPS is primarily comprised of Hispanic, Spanish-speaking students) were more likely to fail than native English speakers. Students in a special education program were also more likely to fail than students not participating in a special education program. On the other hand, there was no correlation between a student's socioeconomic status, as represented by participating in the free and reduced price lunch program, and student failure in ECS. Students who were freshmen were less likely to fail ECS than sophomores, juniors, and seniors; there were no other statistically significant differences by grade level.

There were two behavioral attributes that were statistically significant. Students' overall school attendance rate and their overall cumulative GPA correlated with lowering the probability of failure. Students' whose overall GPA was closer to D or F were much more likely to fail ECS than students whose GPA was closer to A or B.

The primary factors at the course and teacher levels were statistically significant. As teachers continue to teach ECS from one year to the next, the failure rate goes down. Students in classes with a teacher who attended the ECS professional development have a lower probability of failure.

6   Discussion

In order to better understand how student and teacher characteristics interact with the probability of failure, we examined the sensitivity of three characteristics on the probability of failure: students' average cumulative GPA, the number of times a teacher had previously taught ECS, and whether the teacher attended the ECS professional development. Predicted logit values were computed by using the formula in the Methods section to multiply different interval values for these characteristics by the coefficients in Table 5. The predicted logit values were converted to probabilities. Figure 1 show graphs of these probabilities. The blue lines and

bars represent students in classes where the teacher attended the ECS professional development, whereas the yellow represents students in classes where the teacher did not attend ECS PD. Figure 1(a) shows the probability of failure for students with new ECS teachers. Figure 1(b) shows how the results vary with teacher experience for students with a cumulative GPA one point below the average.

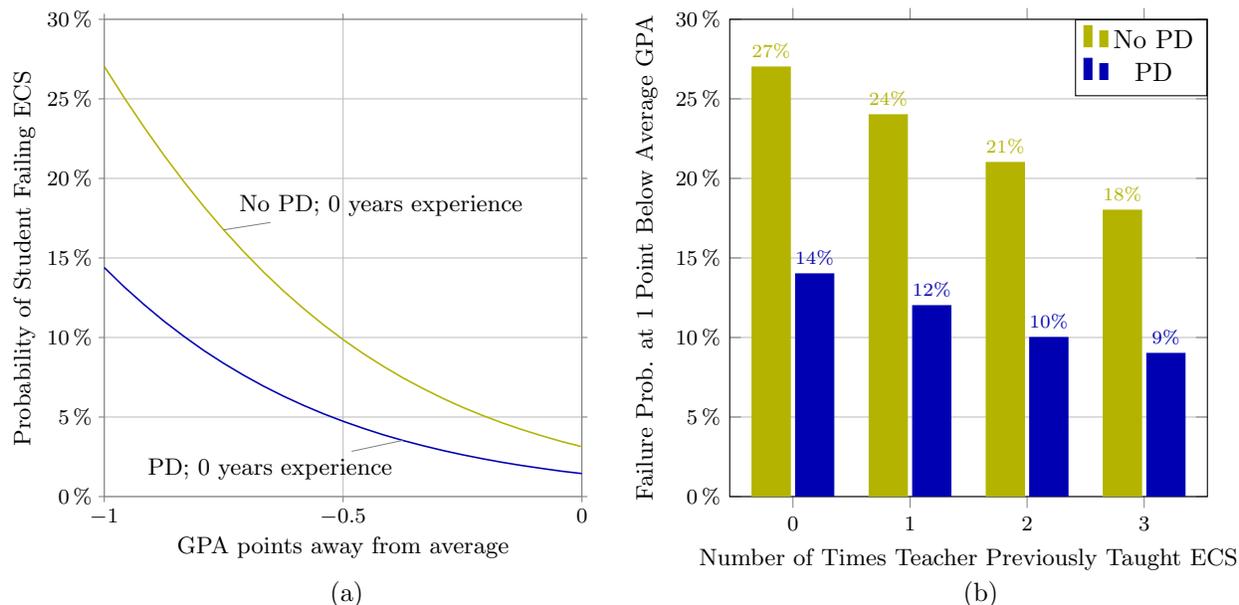(a)   (b)

Figure 1: The graph on the left shows the probability of student failure for new teachers who attended ECS PD (lower blue line) and teachers who did not attend any ECS PD (upper yellow line). The gap in failure rates increases as student GPA decreases, and the graph on the right then focuses on the particularly salient GPA level of 1 grade point below average. The graph on the right shows that, while the failure rate goes down with increases in the number of years a teacher has previously taught ECS, the gap remains between teachers who have and have not attended ECS PD; furthermore, attendance at the PD has a much stronger effect than experience teaching ECS.

Generally, students with an average to above average GPA have a low probability of failing the ECS class regardless of whether the teacher attended ECS PD. It is likely that students who perform well in school can generally adapt to different teaching styles. However, for students with a below average GPA, the probability of failure is vastly different depending on whether the teacher has attended the ECS professional development, with the difference increasing for students with lower GPA's. One of the key elements of the ECS PD is a focus on equity for all students, which means developing a belief that all students can learn computer science and being introduced to strategies for reaching all students, particularly those that are underperforming in school. Teacher experience with ECS is also a significant factor in reducing the failure rate for students, which highlights the importance of principals finding ways to retain teachers in the school and keep them assigned to the ECS course from one year to the next.

7   Conclusion

It is an exciting time for computer science education in the United States. There is a great deal of momentum at all levels of government and wide commitment among the business community towards the goal of ensuring

equitable computer science opportunities for all students. The challenge to reach all students is daunting, and communities are taking a variety of approaches across the country. One large urban district in the United States, Chicago Public Schools, has grown a cadre of qualified teachers over the course of several years and achieved a sufficient critical mass to enact computer science as a high school graduation requirement. Key to achieving the goal of reaching all students through the graduation requirement is to focus on a course specifically designed to provide equitable CS experiences to students, but curriculum is not enough. A teacher professional development program is essential for helping teachers develop equitable teaching practices and implement inquiry-based activities; CPS adopted the *Exploring Computer Science* course and professional development program. With the graduation requirement comes significant responsibility to ensure that students are successful in the required computer science course since failure in the course would prevent students from graduating high school if they are not able to make up the course.

In this paper, we conducted an analysis of the student and teacher characteristics that correlate with student failure in the course. While students have the opportunity to take the course again, it is important to reduce the likelihood that students will fail the class in the first place. At the student level, females have greater success in ECS than male students. African-American students passed the course at a rate equal to Caucasian and Asian students. However, Hispanic students and ELL students failed the class at a higher rate than other students. There is a need for further research to better understand the experiences of Hispanic students in the ECS curriculum.

Attendance and prior performance in school were significant predictors of course failure. Attendance in class is particularly important for ECS as much of the work, particularly in the 2nd semester, is collaborative and relies heavily on class discussion. While students can be given the opportunity to make up missed assignments, it is difficult to replicate the learning that occurs from these group interactions. As the course progresses into the second semester, lack of attendance has an even greater significance which may be contributing to the larger failure rate in the second semester.

While these results related to attendance and GPA may not be surprising given their consistency with research on other core subjects in urban settings, 9th grade ECS students may be benefiting from district-wide efforts to reduce the failure rate of core subjects in 9th grade [1]. Prior research has shown that failure of a core class in 9th grade significantly reduces the probability that a student will graduate from high school at all. Therefore, the district includes a Freshman-On-Track indicator and evaluates schools on the percentage of students who are on track to graduate at the end of freshman year because they passed all of their core classes. The significant resources schools then invest in providing support for 9th graders to pass their classes probably benefit 9th grade ECS students relative to 10–12th grade students, who fail ECS at a higher rate.

At the teacher level, participation in the ECS professional development is significantly correlated with reducing the failure rate. In addition, the failure rates goes down as teachers gain experience in teaching ECS. Creating a cadre of computer science teachers with the right qualifications is, at the same time, critical and difficult to achieve when instituting a graduation requirement in a large district. The ECS professional development program has been successful at preparing teachers from a variety of non-CS backgrounds to successfully provide a meaningful and equitable computer science experience for all students. For the district to be successful at reaching all students through the graduation requirement, it is critical to create an infrastructure to educate and hold principals and decision-makers accountable to ensure teachers fully engage in the professional development and are retained to teach ECS multiple times over the years.

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