Improving College Readiness in Mathematics in the Context of a Comprehensive High School Reform

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This mixed methods experimental study examined the impacts of the Early College High School model on students' college readiness in mathematics measured by their success in college preparatory mathematics courses in the 9th through 11th grades, and disaggregated for academically prepared and underprepared students. This study looked at the longitudinal sample of students who moved from the 9th through 11th grade both in the treatment and control groups. The results show that the reform is having statistically significant and substantively important impacts on students' course-taking and success for both prepared and underprepared students. The impacts of this whole school reform are larger for underprepared students. The results demonstrate that the ECHS reform model is being successful in implementing a universal algebra policy and rigorous college preparation curriculum with students of diverse backgrounds: 38% underrepresented in college minority, 46% low income, and 38% first generation college-goers, and despite of their academic preparedness levels.

The analyses of classroom observations and interviews with mathematics teachers reveal that instruction in the ECHS displays a mix of traditional approaches and rigorous student-centered instructional practices. These results are discussed in the context of debates on benefits and disadvantages of universal algebra policies and student-centered instruction for academically underprepared students.

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Improving College Readiness in Mathematics in the Context of a Comprehensive High School Reform

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Abstract

This mixed methods experimental study examined the impacts of the Early College High School model on students' college readiness in mathematics as measured by their success in college preparatory mathematics courses from 9th through 11th grade, and disaggregated for academically prepared and underprepared students. It analyzed a longitudinal sample of students who moved from the 9th through 11th grade in both the treatment and control groups. The results show that the reform is having statistically significant and substantively important impacts on students' course-taking and success, for both prepared and underprepared students. The impacts of this whole school reform are larger for underprepared students. The results demonstrate that the ECHS reform model has been successful in implementing a universal algebra policy and a rigorous college preparation curriculum with students of diverse backgrounds: 38% underrepresented in college minority, 46% low income, and 38% first generation college-goers, and despite of their academic preparedness levels.

The analyses of classroom observations and interviews with mathematics teachers reveal that instruction in the ECHS displays a mix of traditional approaches and rigorous student-centered instructional practices. These results are discussed in the context of debates on the benefits and disadvantages of universal algebra policies and student-centered instruction for academically underprepared students.

Keywords: early college; college readiness; universal algebra; mathematics instruction

Introduction

In response to global economic demands for more workers with at least some postsecondary education, increasing all students' college and career readiness has been a concern for countries around the world (Clements, Keitel, Bishop, Kilpatrick, & Leung, 2012; Mullis, Martin, & Loveless, 2016). In the U.S., fewer than 1% of 11.6 million new jobs created in the wake of 2008 economic crisis required no postsecondary education (Carnevale, Jayasundera, & Gulish, 2016). Raising mathematics achievement in secondary school for all students, including underperforming students, has been considered an integral part of increasing their college and career readiness. While in some countries, "college" may mean secondary school, throughout this paper, we will refer to college as it is applicable in the U.S. context: a 2-year (community college) or a 4-year institution of post-secondary (tertiary) education.

According to both research and policy documents, college readiness in mathematics involves (but is not limited to) two major components: (1) successfully completing a college preparatory sequence of courses in mathematics and (2) engaging with mathematics content in these courses in a rigorous way, which includes problem solving, developing relational understanding, and sense making and reasoning (Conley, Drummond, de Gonzalez, Rooseboom, & Stout, 2011; Iatarola, 2016; Kamin, 2016; National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010; Silvernail, Batista, Sloan, Stump, & Johnson, 2014).

The results reported in this paper are part of a larger experimental study examining the impacts of the Early College High Schools (ECHS) reform model on student academic and behavioral outcomes in the United States. This comprehensive high school reform model, targeting students underrepresented in college, aims to increase students' college readiness and enrollment in post-secondary institutions. It requires all students to take college preparatory courses, including taking an introductory Algebra course (called Algebra 1 in the U.S.) by the end of the 9th grade. ECHS model also seeks to shift classroom instruction towards increasing rigor and implementing student-centered teaching practices. To ensure students' success in these courses, ECHS provide academic and social supports to students. Experimental studies of the model have shown evidence of positive outcomes for students, including increased achievement in mathematics (Edmunds et al., 2011a, 2011c, 2012).

In the mathematics education community, there are two ongoing debates concerning two policies implemented by ECHS: (1) the universal algebra policy and (2) student-centered instruction. Specifically, it is debated whether these policies are beneficial to all subgroups of students, including low achieving students, and what the conditions are under which these policies are beneficial for different subgroups of students. While the larger study was designed to examine the impacts of the ECHS model in general, the specific analyses reported in this paper contribute to both of these debates and highlight conditions which facilitate students' success. In the quantitative part of this study, students' mathematics performance data were disaggregated to examine differential effects of the ECHS reform model on subgroups of students: those performing at a grade level (referred to as "prepared") and those who did not pass the end of grade math test (referred to as "underprepared"). The performance of ECHS students enrolled in introductory algebra (Algebra 1) or a higher level course at 9th grade, and subsequent college preparatory mathematics courses in later grades, is compared to the control group of students. These analyses will inform the debate about the benefits and consequences of universal algebra policies for both prepared and underprepared students.

In the qualitative part of this study, we examined mathematics instruction in participating early colleges through observations and interviews with teachers. As part of the ECHS reform model in North Carolina, rigorous, student-centered teaching is encouraged to be implemented in all classrooms. Examination of mathematics teaching and learning in these classrooms, in the context of student performance data, will inform the debate about the benefits and disadvantages of rigorous student-centered mathematics teaching for both prepared and underprepared students. Together with the comprehensive academic and social supports provided to students, examined elsewhere (Edmunds, Willse, Arshavsky, & Dallas, 2013), coursetaking policies and rigorous student-centered instruction constitute three essential ECHS elements directly affecting students. This paper aims to examine the combined impacts of these three policies on prepared and underprepared students, discussing them in the context of debates on universal algebra policy and student-centered teaching.

Thus, the overarching question examined in this paper is whether the rigorous mathematics content, combined with the rigorous instructional practices in mathematics classroom, is beneficial to all students, including low achieving students, and what the conditions are under which these practices are beneficial for different subgroups of students. This comprehensive question was studied in the context of early colleges, where both policies are implemented with students underrepresented in college and, in many cases, underprepared for college level work. The specific research questions, therefore, refer to the teaching and learning of underrepresented students in the context of early colleges:

(1) What is the impact of the Early College High School reform model on students' course-taking and academic performance in mathematics in the 9th through 11th grade?

(2) How is the impact of the Early College High School reform model different for students with on-grade and below-grade academic preparedness?

(3) To what extent do early college mathematics teachers implement rigorous and student-centered practices in their classrooms?

In the next section, we begin by describing the early college reform model and research on this model. We then discuss two theoretical and practical debates that place our study in a broader context and provide applicability and implications for these results beyond the ECHS reform model: a debate on how well the universal algebra policy works for prepared and underprepared students, and a debate on the effectiveness of rigorous student-centered instruction versus explicit instruction for students of different ability levels.

Literature Review

Early College High School Reform Model

Description of the Reform

ECHS is a reform model that targets students traditionally underrepresented in college, including those who are the first in their family to attend college, students who are low-income, or members of underrepresented in college minority groups. Many of the students in this target group are also academically underprepared for the rigor of college level courses. ECHS are small, innovative high schools, often located on college campuses, explicitly focused on college readiness for all students. Students apply to these schools and are expected to graduate within four or five years with a high school diploma and up to two years of transferable college credit or an associate degree (a two-year degree or a certificate in a specific career field).

As implemented in North Carolina, U.S. (where this study was conducted), ECHS were guided by the six Design Principles developed by North Carolina New Schools, the non-profit organization supporting the implementation of this model (North Carolina New Schools, n.d.). These Design Principles include: (1) a focus on college readiness, including a default college preparatory curriculum and early access to college credit courses; (2) teaching and learning that emphasize rigorous, student-centered instruction and formative assessment strategies; (3) a personalized learning environment with strong staff-student relationships and academic and social supports for students; (4) a professional working climate where teachers collaborate and collectively take responsibility for student learning; (5) leadership that works to develop a common vision; and (6) use of time, resources and structures to support the other principles, including a small school size of less than 400 students and flexible scheduling.

The first three Design Principles directly affect students. As a result of the college readiness Design Principle, students are not tracked into different levels of courses based on their academic preparedness. Instead, all students are expected to have completed Algebra 1, i.e., introductory algebra (or a higher level course) by the end of 9th grade. Students are expected to continue with rigorous mathematics coursework and may start taking college level math courses such as pre-calculus or calculus in 11th or 12th grades, or even earlier.

With regard to instruction, teachers in ECHS went through the extensive professional development and coaching to implement student-centered instructional strategies in every classroom, called the *Common Instructional Framework*. The Common Instructional Framework's philosophy is represented by the phrase: "*Every student reads, writes, thinks and talks in every classroom every day.*" The specific rigorous student-centered strategies included in the framework (Jobs for the Future, n.d.,a) with descriptions specific to the math classrooms and advanced by the professional development and coaching (North Carolina New Schools, n.d., b) were:

Collaborative Group Work: **S**tudents work in pairs or small groups so that students with diverse skill levels are supported as well as challenged by their peers.

Writing to Learn: Students develop their ideas and critical thinking ability by writing mathematical explanations, justifications, and reflecting on their learning.

Classroom Talk: Classroom talk focuses on discussion of mathematical ideas, their connections, reasoning, and sharing diverse problem solving strategies. Classroom talk takes place in small groups among students or as a whole class including the teacher.

Questioning: Effective questioning elicits students' thinking, facilitates their reasoning, encourages student-to-student discussion, and provides enough time for student thinking and processing.

Scaffolding: Scaffolding helps students to connect prior knowledge and experience with new information. Students are allowed adequate time to grapple with tasks before the most minimal effective assistance is offered.

Literacy Groups: Students read daily, whether they are reading the sections of the text or provided materials that establish context, or articles about math or data. Students are assigned roles to facilitate interpretation, analysis, and discussion of readings.

While students engage in these activities, teachers are expected to use formative assessment strategies to evaluate students' understanding and confusion and provide specific feedback. Embedded in these strategies are features of a rigorous approach to learning mathematics, such as allowing students time to grapple with problems before receiving assistance, and encouraging critical thinking, mathematical explanations, justifications, and reasoning. Therefore, professional development and coaching helped teachers create rigorous, student-centered classrooms, where students were expected to be active learners, and teachers served as facilitators of student learning.

Research on Effectiveness of the Model

Using a randomized control design, prior studies have shown that ECHS schools improved students' academic performance and behavioral outcomes (Berger et al., 2013; Edmunds et al., 2011a, 2011c, 2012) and increased students' engagement with school (Edmunds, et al., 2013). An 18-year longitudinal experimental study of the early college model established that six years after graduating from high school, more early college students earned postsecondary credentials than control students, including associate (2-year) and bachelor's (4-year) degrees. Early college students earned these degrees in less time than control students, while doing equally well academically, as determined by their college grades (Edmunds, Unlu, Furey, Glennie, & Arshavsky, 2020).

In the 9th and 10th grades, more ECHS than comparison students successfully completed college preparatory math and science courses, and more ECHS students enrolled in college preparatory courses in other core subjects. The impacts of ECHS were stronger in mathematics than in any other content area (Edmunds et al., 2012). Additionally, these effects in mathematics were stronger for underrepresented groups, such as first generation and low income students (Edmunds et al., 2012). As a result, early college students earned more college credits while in high school, had higher postsecondary enrollment rates, and attained more postsecondary degrees than control students (Edmunds et al., 2017; Edmunds, Unlu, Phillips, Glennie, & Mulhern, 2024).

The experimental study of the model surveyed ECHS and control students on levels of implementation by their schools of policies reflecting the Design Principles, including rigorous and relevant instruction in all their classes, academic expectations, relationships with teachers, and academic and social supports (Edmunds et al., 2011b). Higher levels of implementation of these specific policies have been shown to be associated with improved students' progression through college preparatory mathematics courses (Arshavsky, Edmunds, Miller, Corritore, 2013).

Survey responses revealed that ECHS students perceived their instruction in all subjects as significantly more rigorous and student-centered than that of control students (Edmunds et al., 2013). The student-centered instruction scale measured such instructional practices as making connections to the real world, having students work collaboratively on projects, and giving students choices about project topics or assignments approaches. The rigorous instruction scale measured students' involvement in higher order thinking, reasoning, explanations, research, presentations, and extensive writing.

At ECHS, the increase in the rigor of student coursetaking and classroom assignments is accompanied by comprehensive supports for students who need them, as part of the Personalization Design Principle (Edmunds et al., 2010). In addition to extensive tutoring, often provided by ECHS teachers to struggling students, academic supports in ECHS were integrated into the school day, both during and outside of regular instructional time (Edmunds et al., 2013). In addition to higher levels of expectations and supports reported on surveys, interviews with students across early colleges revealed that their teachers expected them to succeed in their classes and would not accept students' failure. In many early colleges, struggling students were required to get academic support, with special periods scheduled during the day for this purpose in some ECHSs. Most students felt their teachers genuinely cared about their academic and personal success, which motivated students to work harder on challenging academic assignments (Edmunds et al., 2013). As a result of positive relationships with teachers and strong academic supports, students at ECHS were significantly more engaged (Edmunds et al., 2013) and invested more effort in their academic work than control students, leading to higher success rates in completing college preparatory math classes.

The current study presents new analyses not reported previously and adds to the body of early college research in two ways. First, it investigates the impacts of ECHS on the mathematics achievement of a longitudinal sample of students in college preparatory classes from grades 9–11, disaggregated by academic preparedness (prepared vs. underprepared students), tracking their progress in mathematics. Second, it explores students' mathematics performance in the context of the instruction they experience in mathematics classrooms, as reported by teachers and observed by independent researchers.

Universal Algebra Policies

Algebra is often viewed as a gateway course to advanced mathematics course-taking and college opportunities (National Mathematics Advisory Panel, 2008). Studies suggest that only 5% of students who have not successfully completed (either did not take or failed) the introductory Algebra 1 course by the end of the 9th grade are able to catch up and complete a college preparatory sequence of math courses by graduation (Finkelstein & Fong, 2008). Studies on algebra course-taking suggest that enrollment in algebra in eighth or ninth grade is lower among non-Asian minorities, economically disadvantaged students, and children of parents with a lower educational background, thus limiting these groups' access to more rigorous mathematics courses and ultimately to college (Lee & Bryk, 1989; Oakes, 1990). Therefore, policies regarding access to algebra in eighth or ninth grade are often viewed as an equity issue (Stein, Kaufman, Sherman, & Hillen, 2011). These imbalances are at least partially explained by these students' under-preparedness for the introductory algebra course (Loveless, 2008).

To address this equity issue, some districts and states in the U.S. have adopted a policy of universal algebra access (sometimes called "Algebra for All") either in the ninth grade (e.g., in the Chicago Public School District, see Nomi, 2012) or in the eighth grade (e.g., in the state of California, see Domina, McEachin, Penner, & Penner, 2015 or Liang, Heckman, & Abedi, 2012.) The benefits of taking Algebra 1 early are confirmed by some studies (Rickles, 2013; Smith, 1996). Using the National Education Longitudinal Study of 1988 (NELS:88) data, Rickles (2013) investigated the effects of taking Algebra 1 in the 8th grade on subsequent student mathematics achievement in the 12th grade, measured by a math test. Rickles (2013) used propensity score matching to create treatment and control groups and account for the selectivity of students in the 8th grade Algebra classes. The study found uniformly positive effects of early exposure to algebra for all subgroups of students.

Other studies indicated that although early enrollment in algebra is generally beneficial for later student outcomes, these benefits may vary among subgroups of students. In particular, in Chicago, the achievement of higher ability students declined as a result of the policy (Nomi, 2012), while other studies suggested that lower achieving students may not benefit as much as higher achieving students (Gamoran & Hannigan, 2000; Loveless, 2008; Williams et al., 2011). Specifically, Williams et al. (2011) analyzed 8th grade California students' Algebra 1 test performance based on their prior achievement. They showed that well prepared students scored proficient or better on the test, while underprepared students placed in Algebra 1, generally scored below the basic level. Loveless (2008) demonstrated similar trends with NAEP data. Other studies reported positive effects of taking algebra for all students with smaller benefits for underprepared students (Gamoran & Hannigan, 2000; Liang, et al., 2012). Liang, et al. (2012) found, using California data, that increases in the number of students taking Algebra 1 in the 8th grade led to increases in both course-taking and successful completion of higher level mathematics courses in the 9th-11th grades. However, the number of students taking and successfully completing these courses beyond Algebra 1 declined as students progressed through high school.

As enrollment in algebra courses in eighth or ninth grade has increased nationally over the past 10-20 years, average algebra achievement has decreased, as a broader range of students received access to the courses (Nord et al., 2011; Rampey, Dion, and Donahue, 2008; Walston and McCarroll, 2010). Also, in districts with universal algebra policies, the absolute number of students taking and succeeding in algebra has increased, while the failure rate of students who took algebra has also increased (Ham &Walker, 1999; Stein, et al., 2011).

Thus, research remains inconclusive on the differentiated effects of the universal algebra policies on higher and lower achieving students. Additionally, the effects of universal algebra may be moderated by additional policies implemented in conjunction with it. Many, if not all, of the positive effects reported in the literature were facilitated by additional instructional time and support for struggling students, such as catch-up courses, double-dose math, or additional tutoring time (Balfanz, Legters, & Jordan, 2004; Durwood, Krone, & Mazzeo, 2010; Nomi & Allensworth, 2009, 2013; Nomi, Raudenbush, & Smith, 2021). These studies found that providing double dose algebra instruction to high poverty students reduced their failure rate in the 9th grade Algebra 1 course (Balfanz, Legters, & Jordan, 2004; Nomi & Allensworth, 2009). However, the nature of instructional practices in mathematics classes that include a broader range of students under universal algebra policies remains largely unexplored (Litke, 2019; Stein, et al., 2011). The question that still needs to be answered is not just whether higher and lower achieving students all benefit from a rigorous mathematics curriculum that includes Algebra 1 in or before the 9th grade but under what conditions the majority of students will succeed in this gateway mathematics course required for their further success in and beyond high school, thus achieving greater equity for all students. The role of instructional strategies in supporting the increased rigor of mathematics curriculum for a broader range of students is still underexamined.

The current study addresses this gap by exploring the impacts on students' mathematics performance, differentiated by student preparedness, of a whole school reform mandating a universal algebra policy. The study also examines mathematics instruction that accompanies rigorous coursetaking for a broad range of students, providing a look into the conditions necessary to support students' success.

Rigorous, Student-Centered Instruction

As a broader range of students, including low performing students, receive access to algebra in earlier grades, it is important to investigate instructional strategies that ensure students' success in these classes and prepare them for colege and careers. With new college-preparatory Common Core State Standards in place in many U.S. states (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010), multiple reports call for increasing the rigor of mathematical content and allowing students a more active role in mathematics classrooms, often called student-centered instruction, as essential components of increasing students' college and career readiness (Hess, Gong, & Bayerl, 2014; Marzano & Toth, 2014; National Center for Educational Achievement, 2009; The Education Alliance, 2006). In studies of college readiness, rigorous mathematics learning has been described by the emloyment of processes such as genuine problem solving (finding a solution, a path to which is not clear from the beginning); relational and conceptual understanding; making sense of problems, procedures, and relations; and reasoning and justification for mathematical statements (Conley, Drummond, de Gonzalez, Rooseboom, & Stout, 2011; Hess, 2023; Kamin, 2016; McCormick, & Lucas, 2011).

The term "student-centered learning" is used in the literature to encompass a variety of approaches, including students teaching each other in cooperative groups and other arrangements; students engaged in active learning and processing of information; students being owners of their learning and having choices in their assignments and/or ways to perform them; personalized and differentiated instruction, etc. (Walters et al., 2014). Some studies indicate that coupling student-centered instruction with rigorous treatment of mathematics content may provide increased benefits (Boaler, 2006; Ikemoto, Steele, & Pane, 2016; Walters et al., 2014; Williams, et al., 2022). Walters and colleagues (2014) reported higher student engagement and better performance in solving complex problems in student-centered classrooms, characterized by a supportive and respectful learning environment and students' meaningful engagement with mathematics (Walters et al., 2014). Ikemoto and colleagues (2016) reported that higher student performance in Geometry was associated with learner-centered practices (characterized by collaborations and student presentations) emphasizing mathematical connections. Boaler (2006) demonstrated associations between rigorous student-centered instruction, characterized by students working in groups on complex conceptual problems, with improved learning. Student-centered instruction showed stronger positive relationships with open-ended measures and problem solving skills than with multiple choice and procedural skills in mathematics (Le, Lockwood, Stecher, Hamilton, & Martinez, 2009).

At the same time, there is still no consensus on whether rigorous, student-centered instruction is beneficial for all ability groups, including low achieving students. The report of the National Mathematics Advisory Panel (2008) devoted a section to resolving the specific controversial issue of whether teacher-directed instruction or student-centered approaches are more effective for average and low-achieving students. According to the Panel, teacher-directed or explicit instruction is characterized by the teacher providing clear models and multiple examples for problem-solving, followed by extensive practice with similar problems. Students then demonstrate solutions out loud and receive feedback on their solutions. Student-centered instruction was defined as “instruction in which students are primarily doing the teaching” (National Mathematics Advisory Panel, 2008, p. 45). The Panel considered only the most rigorous research that directly compared these two approaches and concluded that there is not enough evidence to favor one of these approaches over another, and that neither should be used exclusively. At the same time, the Panel concluded that specific strategies within these approaches, such as collaborative group learning and formative assessment, have been effective at certain grade levels and under certain conditions with all students, including average and low-achieving students, while explicit instruction has been consistently shown to be effective for low achieving students. The Panel recommended that, along with other strategies, low achieving students should receive explicit instruction regularly to build foundational skills and conceptual knowledge. The Panel also noted that few rigorous research studies were conducted on effective instructional strategies for low achieving students and that more studies are needed to determine what works and under which conditions.

The Panel's conclusions were supported by other research not comparing these two approaches directly (Baker, Gersten, & Lee, 2002; Kirschner, Sweller, & Clark, 2006; Kroesbergen, Van Luit, & Maas, 2004; Slavin, et al., 2009; What Works Clearnighouse, n.d.).

In summary, literature indicates that neither student-centered nor explicit (or traditional) instruction should be used exclusively with either average or low performing students. Specific student-centered instructional practices, such as formative assessment and collaborative learning, combined with the rigorous approach to content may be beneficial for all groups of students, but explicit instruction can also be effective for low performing students. There is still insufficient research basis to determine an appropriate balance of rigorous, student-centered and explicit instruction for achieving desired student learning outcomes for average and low-achieving students.

Teachers working in North Carolina ECHS in this study went through intensive professional development and coaching to implement rigorous student-centered instructional strategies, as described in the section on the early college reform model above. This paper provides a qualitative account of how teachers implemented these strategies in their mathematics classrooms.

In this study, we were able to examine the effects of the universal algebra policy, adopted by ECHS, in the context of instructional strategies and supports provided to both prepared and underprepared students. By describing these instructional strategies and resulting student performance, this paper contributes to the discussion on instructional approaches that help to support a rigorous college preparatory mathematics curriculum for and expand college readiness to a broader group of students thus increasing the equity of access to higher education for underrepresented in college groups.

Methodology

This study uses an explanatory mixed methods design, where the qualitative data are intended to explain the findings of the quantitative data (Creswell, Plano Clark, Gutmann, & Hanson, 2003). The specific methods used to answer each of the research questions are described below.

Research Questions 1 & 2: Impacts of ECHS on Students' Performance in Mathematics

Sample

This paper reports results from an IES-funded longitudinal experimental study of the impact and implementation of North Carolina's ECHS model. Participating schools agreed to use a lottery to select students, and the study is tracking outcomes for students randomly accepted into the program (treatment) and those not accepted who enrolled in some other school in the state, typically in the same district (control). The schools sometimes screened out exceptional and severely underprepared students before the random assignment was conducted by the research team. In some cases, the research team conducted stratified lotteries to help schools admit a certain proportion of students who are members of groups underrepresented in college; in other cases, the entire district had a large proportion of such students.

In this paper, we include results from analyses completed on a longitudinal sample of 1,434 treatment and 995 control students who applied to 19 early colleges for the fall of 2005 through 2009. For this analysis, all students who were originally in the lottery were included, unless we had evidence that they had transferred to a private school, homeschool environment, or moved out of state. There were statistically significant differences in three background characteristics between the treatment and control groups: exceptionality status, percent retained prior to the 9th grade, and passing the 8th grade math test (4 percentage points higher in the treatment group). There were no statistically significant differences in any other background characteristics, as can be seen in Table 1. There were significantly more girls than boys in both groups. All covariates (categories in Table 1) are adjusted for in the analyses.

Table 1. *Longitudinal Sample Characteristics, by Treatment Status*

	Whole Sample	Treatment Group	Control Group	T-C Difference	
	Mean	Mean	Mean	Difference	P-Value
Race & Ethnicity					
American Indian	1.1%	0.8%	1.3%	-0.5%	0.18
Asian	1.0%	1.0%	1.1%	-0.1%	0.89
Black	27.7%	28.2%	27.0%	1.2%	0.49
Hispanic	7.9%	8.4%	7.3%	1.1%	0.29

Multi racial	3.2%	2.8%	3.7%	-0.8%	0.21
White	59.1%	58.8%	59.6%	-0.9%	0.65
Gender					
Male	41.0%	40.8%	41.2%	-0.4%	0.82
Age	15.33	15.32	15.35	-0.03	0.08
Socioeconomic Background					
First Generation College	40.2%	39.2%	41.5%	-2.2%	0.27
Free/Reduced Price Lunch Eligibility	49.0%	49.3%	48.7%	0.6%	0.76
Exceptionality					
Disabled/Impaired	2.2%	1.7%	2.9%	-1.2%	0.04*
Gifted	8.3%	7.7%	9.0%	-1.3%	0.20
Retained prior to 9th grade	3.7%	2.9%	4.7%	-1.7%	0.01*
8th Grade Achievement					
Math - Z score	-0.01	-0.01	0.01	-0.02	0.61
Reading - Z score	0.00	0.01	-0.02	0.03	0.46
Math - pass	81.7%	83.4%	79.4%	4.0%	0.01*
Reading - pass	80.3%	81.2%	79.1%	2.0%	0.18

Data Sources

Students' academic performance in mathematics was tracked through student-level data collected by the North Carolina Department of Public Instruction and housed at the North Carolina Education Research Data Center.

Analyses

For the quantitative analyses, we report the unadjusted means for each group—treatment and control—as well as adjusted impact estimates calculated using regression analyses that incorporate background characteristics and site-level indicators. This study primarily uses an intent-to-treat (ITT) analysis. Intent-to-treat, which is considered the standard for education policy studies (Institute of Education Sciences, 2005), keeps all study participants in the group to which they were originally assigned (treatment or control), regardless of whether participants actually received the entire intervention or not. In this study, any students initially assigned to the early college were included in the treatment group, even if they changed their mind and did not go (they are called no-shows) or if they later left the school after being enrolled for some. In addition, students who were initially identified as being in the control group remained in the control group for analysis purposes, even if they later attended the early college for any reason (they are called crossovers).

If we were not doing an intent-to-treat analysis, the impact of the model would be shown only for those students who chose to remain in the school. These students might be different in some systematic way from students who decided not to attend or who left (i.e., more motivated, a better fit with the school). As the ITT approach ignores no-shows and crossovers, it may understate the early college effect on those who ended up participating in the intervention but it ensures that the effect is not overstated because of student attrition (Hollis & Campbell, 1999).

Research Question 3: Mathematics Teaching and Learning

Data Collection

In the larger study, site visits to ECHS were conducted to evaluate the extent of implementation of the six early college Design Principles. The data on mathematics instruction were collected through classroom observations and interviews with mathematics teachers. The observations were conducted by two researchers. After each observation, the observational notes were compared and reconciled by the two observers. Interviews were recorded and transcribed.

Sample

Site visits were conducted in 17 out of 19 ECHS in the study (two schools agreed to participate in quantitative data portion only). In each school, we observed and interviewed one math teacher, selected by the principal. In one school, the teacher was observed but not interviewed due to scheduling issues. Most of the schools were very small and often had just 1-2 math teachers. Typically, teachers most involved in ECHS professional development were selected for participation. The interviews and observations were conducted only in the treatment schools, and each teacher was observed once for an entire lesson. We acknowledge that one observation is not sufficient to characterize the instruction of an individual teacher, as this would require repeated observations for reliability (Kane & Staiger, 2012). However, our goal was to obtain a snapshot of instructional practices across all study schools rather than compare the instruction of individual teachers or compare this instruction to that received by control students.

Among the 17 observed classrooms, three were using reform curricula (Core Plus) in Integrated Math courses. In addition, we observed one Algebra 1 class, six Algebra 2 classes, and seven Geometry classes. Table 2 shows the demographic characteristics of the observed classrooms.

Table 2. *Demographic Characteristics of Observed Classrooms*

Characteristic	Mean	Median	Range
Class Size	14.2	15	7 - 26
Percent Girls	59%	60%	40 – 82%
Percent Minority	40%	44%	0 – 85%

Measures

Two interview questions addressed instruction and assessment, and the rest addressed other non-instructional issues. The responses related to classroom instruction were analyzed for this paper. The interview question about instruction was open ended: “If I were to ask you to describe a typical class, how would you describe your instructional style?” Teachers were further probed about conducting lectures, group work, and hands-on activities. The second question asked about assessments: “Describe how you use assessments in your classroom.” Formative assessment was often a focus of professional development, and teachers were expected to at least partially implement its components (explicitly setting student learning goals, frequently evaluating student learning and understanding, providing descriptive feedback, and conducting self- and peer assessment).

The observation protocol instructed observers to “keep a running record of classroom activities, describing them in the categories of student work, lesson content, lesson instruction, assessment, and personalization.” The protocol is provided in Appendix A. These running records were designed to pay specific attention to:

- Students’ engagement in higher order thinking, reasoning, and explanations;
- The extent to which lessons allow students to apply facts/terminology to solve complex problems;
- Collaboration with other students and the nature of that collaboration;
- Engagement in “elaborated communication” (explaining thinking, writing, presentations, etc.);
- Use of any assessment strategies; and
- Any indications of the teacher adjusting instruction based on informal assessments.

The training for the four observers conducting visits consisted of meetings prior to observations to discuss specific examples for each category, followed by discussions after each observation conducted by a pair of observers.

Analyses

The interview data were transcribed into Atlas.ti software and independently coded for main themes by two researchers. The two researchers then met and reconciled their codes. Teachers used their own words in describing their typical classroom, and their responses were analyzed for descriptions of instructional practices they used, employing a combination of deductive and inductive coding. We began with codes that represented expected changes in instruction, including the six strategies that were part of the Common Instructional Framework, which were intended to be implemented in all classrooms as part of the ECHS’ teaching and learning principle. We then supplemented the codes identified a priori with additional codes that arose out of the data.

The observational data consisted of narrative notes describing classroom activities in the categories listed above. These notes were coded by two researchers according to the coding guide describing specific instructional strategies and features (provided in Appendix B). The codes for the analysis of observational data were pre-determined based on instructional features named by teachers during the interviews and that were the focus of this study, such as: collaborative work, student communication, collecting evidence of student learning, rigorous instruction, and explicit instruction. The activities were coded for presence only; there was no coding for the duration or intensity of these activities.

Approximately 20% of the lessons were consensus-coded to achieve initial inter-rater reliability. The remaining lessons were independently coded, with 78% exact agreement between the coders. The discrepancies were then resolved through discussion, and codes achieved by consensus were used for the observational data.

Results

Research Questions 1 and 2: Impacts of ECHS on Students' Performance in Mathematics

Table 3 shows the results for 9th grade, 10th grade, and 11th grade mathematics outcomes for the longitudinal sample of students. For each course, we report two outcomes: the percentage of all students in the grade in our sample who have taken the course (take-up) and the percentage of all students in the grade (not only those who have taken the course) who have passed the course (progress). The college preparatory mathematics sequence includes at least Algebra 1 or higher in the ninth grade, and at least one additional subsequent course in the sequence of Algebra 1, Geometry, Algebra 2, or equivalent integrated courses in the 10th and 11th grades.

Table 3. *Impacts of Early College on 9th, 10th, and 11th Grade Outcomes in Mathematics*

College Preparatory Mathematics Courses		Adjusted Mean		Adjusted Impact
		ECHS (N=1434)	Control (N=995)	ITT Estimate
9th Grade	%At least one course take-up	97.0	90.2	6.8*
	% At least one course progress	94.45	89.2	5.25*
10th Grade	%At least two courses take-up	91.8	84.3	7.5*
	% At least two courses progress	89.7	81.3	8.4*
11th Grade	% At least three courses take-up	91.6	85.3	6.3*
	% At least three courses progress	89.0	81.2	7.8*

* Denotes statistically significant differences at the $p<0.05$ level.

As seen in Table 3, all impacts of ECHS are statistically significant and range between 5.25 to 8.4 percentage points. Almost all ECHS students (97%) attempted and 94.5% of students succeeded in completing at least the Algebra 1 course by the end of the ninth grade. The proportion of students successfully completing subsequent courses in the college prep sequence decreased slightly in the 10th and 11th grades, but was still around 90%, while the proportion of control students successfully completing courses in the college prep sequence declined from 89% in the 9th grade to 81% in the 10th and 11th grades. Consistently through the grades, the difference between the proportion of students who attempted and those who successfully completed the math course sequence was 2 percentage points for ECHS students and 4 percentage points for the control group.

Table 4 provides differentiated results for two subgroups of students: "underprepared" and "prepared for the 9th grade." Students who did not pass either or both 8th grade reading and math tests were defined as "underprepared," while students who passed both tests were defined as "prepared for the 9th grade." Table 4 presents three groups of results: (1) impact of ECHS on underprepared students; (2) impact of ECHS on prepared students; and (3) comparison of ECHS' impacts on these two groups.

Table 4. *9th - 11th Grade Subgroup Mathematics Outcomes: Underprepared and Prepared Students*

College Prep. Math Courses		Underprepared Students			Prepared students			Differential Impact
		Adjusted Mean		Adjusted Impacts	Adjusted Mean		Adjusted Impact	
		ECHS (N=246)	Control (N=194)	ITT Estimate (A)	ECHS (N=1022)	Control (N=676)	ITT Estimate (B)	Underprepared –Prepared (A-B)
9th Grade	% Take-Up	87.5	75.6	11.9	99.3	95.3	4.0*	7.9
	% Progress	81.1	73.6	7.5	98.5	94.7	3.8*	3.7
10th Grade	% Take-Up	73.1	57.1	16.0*	97.7	92.5	5.2*	10.8
	% Progress	71.9	52.9	19.0*	96.6	90.6	6.0*	13.0*
11th Grade	% Take-Up	76.6	61.2	15.4*	96.9	92.2	4.7*	10.7*
	% Progress	69.8	55.4	14.4*	95.9	89.2	6.7*	7.7

* Denotes statistically significant differences at the $p<0.05$ level.

These results show that the impacts of ECHS on course-taking and course progress are consistently positive for both groups of students in all three grades, and they are statistically significant for prepared students in grades 9–11, and for underprepared students in grades 10–11. The impacts are consistently higher for the underprepared group.

Research Question 3: Mathematics Teaching and Learning

Qualitative data included interviews with mathematics teachers and observations of their classrooms, which we will discuss in turn.

Interviews with Mathematics Teachers

As expected, the rigorous student-centered instructional practices emphasized in professional development and coaching were often mentioned in interviews by the sixteen mathematics teachers in 16 different early colleges as they described their typical classroom routine. The three most frequently mentioned strategies included: (1) teacher as a facilitator (56%); (2) group work (69% of teachers mentioned it); and (3) classroom talk (56%). Teachers described their role as a facilitator in different ways. For example, one teacher actively supported her students in engaging with each other: “So we're constantly working on them [students] explaining their thinking, and learning how to communicate with each other, and doing a lot of group work. I have kept my tables in groups the entire semester so far.” Another teacher noted that she was trying to change the role she played: “So between the group working the assignments, there is usually … hopefully no more than 15 or 20 minutes with me up in front talking, demonstrating, and I just try to facilitate whatever the goal for the unit, or the day, or the remediation is…”

Working in groups was a common practice, seen as having substantial benefits, as described by one teacher:

> … there's definitely a dialogue there, and adjustment, and editing what they - and part of that comes from being able to talk to each other in the group where it's safe, and they're not having to talk out loud in front of the class, and so that builds their confidence with explanations.

These teachers' quotes illustrate that they embraced student-centered approaches to instruction and tried to implement them consistently in their classrooms. Math teachers also described the use of writing (mentioned by 44% of interviewees) as a key rigorous instructional strategy. Often, writing was used in the exit tickets where students had to explain what they understood well and where they were confused during the lesson. One teacher shared, "Sometimes I make them write it out in words. 'Tell me in a paragraph or two how to solve a system of equations using the substitution method.'"

Approximately a third of instructors also described using projects and investigations as part of their math instruction. One teacher described the investigations in her Algebra class:

> In Algebra, we've pulled in a bunch of different stuff, small group, large group, groups of two, groups of four, groups of six. Last week we did two different labs in Algebra. One was a group of two. They took a pipette and they measured drops of water for circumference and the number of drops to show linear regression. Then we did dropping a super ball from various heights and mapping that.

One teacher described how she let her students continue to revise a project until they had developed the necessary level of understanding:

> And if we're working on a project, most of the time I will allow the kids to turn in whatever it is in as many times as it takes for them to get it right, as long as they can understand and explain, well, here is where I was messing up before.

A number of teachers connected the shifts they were making towards rigorous student-centered instruction to their participation in professional development, as one of them noted, “But to me the mind shift came in giving up control. That was one of the things that I had to learn.” Another teacher reflected:

> I think my teaching practice has been able to step up a notch and to really try to do new things that are valuable, to let the kids know that they're valuable, to get them to talk about it, to get them to learn, and do all the work instead of me just to throw stuff at them all the time.

A few teachers mentioned that, along with the student-centered approaches, they also use traditional methods to a varying extents, such as lecture, direct instruction, problem-solving/practice, and checking homework answers. These interviews, together with observations, illustrate that teachers are at different stages of transition from traditional to student-centered teaching with a few teachers using mostly traditional methods, and many combining various approaches.

Although not asked directly, a few teachers mentioned the impact on students of these instructional strategies. These teachers noted that, as a result of using these strategies, students were better able to explain their thinking and better communicate in groups, stay on task while the teacher attended to others, and begin to think mathematically. For example, one teacher said her students were "…on task considerably more than when I was standing at the board, explaining the problem they didn't know how to do." Another commented, "They may not do great every day, but they're really starting to think mathematically." A third noted that group work helped students feel less anxiety about math: "I think it settles them down more and it relaxes them so they don't feel - because a lot of them have bad feelings about math. They've never done well in math and they've always felt, 'I can't succeed here'."

Observations of Mathematics Classrooms

In addition to the interviews, we also observed instruction in 17 teachers' classrooms. As described in the Methods section, observations were coded to capture examples of the following instructional features: rigorous instruction; collaboration with other students and the nature of that collaboration; engagement in "elaborated communication" (explaining thinking, writing, presentations, etc.); explicit instruction; and collecting evidence of student learning.

Analyses of observational notes confirm the instructional emphases that teachers communicated during the interviews. Table 5 presents the instructional strategies that were recorded, the number of classrooms in which they were observed, and examples of these strategies.

Table 5. *Instructional Strategies and Features Observed in the Classrooms*

Instructional strategy	Number (Percent) of classrooms	Examples of strategy
Collaborative work	12 (71%)	Solving problems together, helping each other (observed in 8 classrooms); Identifying mistakes made in a solution to a problem in a group; Checking each other's homework or classwork (2 classrooms); Hands-on group activity (2 classrooms).
Student communication	15 (88%)	Written presentation of the student-designed problem on a poster; Small-group discussion among students; Small group presentation; Whole-class discussion.
Explicit instruction	14 (82%)	The teacher solves multiple examples on the board and then students complete worksheets with similar problems.
Collecting evidence of student learning	15 (88%)	Checking and questioning groups of students as they worked; listening as students explained their thinking and solutions to the peers; Collecting written exit tickets (observed in 2 classrooms); Simultaneously collecting responses from the whole class (thumbs up or down; standing up for correct and sitting down for incorrect

		answers); asking individual students or groups to submit answers online.
Rigorous instruction	7 (41%)	Peer teaching - Students are instructors, asking each other questions; Teacher asks a whole class to create a generalization, a rule, from a set of numeric problems; Students are asked to justify their answers and prove geometric relationships or conjectures: “How do you know, what’s your reason?”

Rigorous instruction was observed least frequently (in seven classrooms or 41%). Collaborative work was observed in 12 (71%) of classrooms. Other instructional features were observed in most classrooms (82 – 88%). In nine classrooms (53%), both explicit instruction and collaborative work were observed.

To examine the extent to which student-centered strategies were correlated with rigorous instruction, we analyzed co-occurrences (Crosstabs) of student collaborative work (as a proxy for student-centered instruction) and explicit instruction with instructional rigor or its absence. Table 6 presents pairwise Crosstabs between these instructional features.

Table 6. *Cross-tabs of the Collaboration, Explicit Instruction and Rigor*

	No rigor	Rigor
No collaboration	4	1
Collaboration	6	6
No explicit instruction	1	2
Explicit instruction	9	5
Total	10	7

Collaborative classrooms were as likely to be rigorous as not rigorous, while non-collaborative classrooms tended to be not rigorous. Classrooms with explicit instruction were less likely to be rigorous. In three classrooms (18%), all three features were observed. Due to the small sample sizes, none of these differences were statistically significant.

Thus, early college classrooms demonstrated a mix of instructional strategies, such as collaborative groups, collecting evidence of student learning (student-centered approaches), and explicit instruction, which were observed in many of the same classrooms. In a number of classrooms, students worked collaboratively on not very cognitively demanding assignments and attended to procedures.

Discussion

The contributions of the results of this study to the body of research on college readiness in mathematics are discussed as they relate to the overarching research question of this study: whether the rigorous mathematics content combined with the rigorous instructional practices is beneficial to all students, including low achieving students, and what the conditions are under which these practices are beneficial for different subgroups of students.

The discussion will also contribute to two ongoing debates: the debate on the benefits and consequences of the universal algebra policy for prepared and underprepared students and the debate on the benefits of the rigorous student-centered instruction for these same groups of students.

Effects of Universal Algebra Policy at ECHS on Prepared and Underprepared Students

The first result of this paper shows that, compared to control students, students at ECHS are significantly more likely to enroll in and succeed in the college preparatory mathematics sequence from the 9th through 11th grades. This study analyzed a longitudinal sample of students who moved through the 9th through 11th grades in both the treatment and control groups. Due to its universal algebra policy, nearly all ECHS students attempted and successfully completed at least the introductory algebra course by the end of their 9th grade. The proportion of students at ECHS successfully completing subsequent courses in the college preparatory sequence remained high (90%), significantly higher than that of control students (81%). In higher grades, the gaps between ECHS and control students increased, both in terms of mathematics coursetaking and success. The impacts of ECHS were even more pronounced before the state of North Carolina implemented a revised high school graduation policy requiring all students to complete four college preparatory mathematics courses before graduation: Algebra 1, Geometry, Algebra 2, and one course beyond the Algebra 2 level (Arshavsky et al., 2014).

Second, the study provides evidence that the positive impacts of the ECHS reform model on mathematics performance are much stronger for students who were underprepared for high school—those who did not pass either or both eighth-grade reading and math tests. In all three grades, the impacts of ECHS were higher for underprepared students than for prepared students. These results suggest that, in the context of this reform, lower achieving students benefited more from the ambitious mathematics coursetaking policies than higher achieving students, which contrasts with the findings of other studies suggesting that lower-achieving students may not benefit as much as higher-achieving students (Gamoran & Hannigan, 2000; Loveless, 2008; Liang et al., 2012; Williams et al., 2011).

Our results demonstrate that the ECHS reform model is successfully implementing a universal algebra policy as part of the universal college prep math policy, despite the demographics of enrolled students: 38% underrepresented in college minority, 46% low-income, and 38% first-generation college-goers, as well as their academic preparedness levels.

Thus, these results provide strong evidence that universal algebra, as part of a universal college preparation policy, under the right conditions, can lead to significant increases in student learning of mathematics among underrepresented students in college. This is consistent with prior research showing that the impacts of the ECHS on mathematics course-taking are significantly higher for low-income than non-low-income students (Edmunds et al., 2011c). So, what are the right conditions for student success? As pointed out in the literature review, one of the most important conditions to support rigorous mathematical content is rigorous student-centered instruction, which was also a key target of this reform model. The next section discusses the implementation of instructional strategies in early colleges.

A mix of Rigorous Student-Centered and Traditional Instruction in ECHS Mathematics Classrooms

Finally, this study explored how the placement of all students into a college preparatory mathematics course sequence at ECHS was accompanied by changes in instruction. The paper presents a descriptive snapshot of instructional practices based on observations of and interviews with math teachers across 17 early colleges in our study and does not attempt to establish causal relationships between instruction and student achievement.

During the interviews, mathematics teachers conveyed that, as a result of professional development supporting the ECHS reform, most of them shifted instruction toward more rigorous student-centered strategies. Teachers discussed how professional development and coaching they received helped them emphasize mathematical talk among students and become facilitators in their classrooms. Teachers' quotes illustrated their focus on building students' active roles in learning, working in groups, teaching each other, providing explanations for their mathematical solutions and ideas, and building students' mathematical confidence.

Independent observations confirmed teachers' reports. Approximately 70% of teachers talked about implementing group work in their instruction, and in the same proportion of classrooms, students were observed collaboratively working on assignments and extensively communicating with each other. In 88% of the classrooms, teachers were also observed collecting evidence of student learning. In interviews, teachers reported using traditional teaching methods such as lectures, explicit instruction, and practice worksheets, and 82% of teachers were observed using these strategies in their classrooms. At the same time, in 53% of classrooms we observed a mix of collaborative learning and explicit instruction.

It is clear from the timing of our visits (we visited schools in the first through third year of their existence) and from teachers' remarks during interviews that they were in transition from traditional to more rigorous student-centered instruction. While creating a rigorous student-centered classroom environment was a goal expressed in the Powerful Teaching and Learning Design Principle of the ECHS model, not all observed teachers fully embraced this goal. Some teachers were still using entirely traditional instructional styles, and a few employed mostly student-centered pedagogy, with the majority of teachers using a mix of traditional and student-centered approaches. We do not know whether this mix of instructional strategies was an indication of transition or a balance of instructional practices that teachers intended to maintain. Our findings are consistent with previous research on the effectiveness of professional development in general and for mathematics teachers in particular. This research shows that creating instructional change requires a substantial number of hours of professional development and significant time for implementation (Lynch, Hill, Gonzalez, & Pollard, 2019; Timperley, Wilson, Barrar, & Fung, 2007; Weiss & Pasley, 2006).

While higher order thinking and complex problem solving were also emphasized in professional development and mentioned as a focus of instruction by a number of teachers, rigorous instruction was observed in only 41% of all classrooms. Classrooms in which explicit instruction and an absence of collaboration were observed tended to be less rigorous.

As observed in our sample, more classrooms demonstrated behavioral changes associated with student-centered learning than changes in the level of rigor. Collaborative learning, classroom talk, and collecting evidence of student learning were observed much more often than a focus on higher order thinking and complex problem solving. Often, in collaborative groups students were observed working on routine problems and tasks or checking each other's work. This finding supports previous similar findings on the challenges implementing of rigorous and cognitively demanding instruction (Hiebert et al., 2003; Pane, McCaffrey, Slaughter, Steele, & Ikemoto, 2010). Despite the moderate observed frequency of rigor in mathematics classrooms, students' survey responses seem to indicate that, in general, student-centered and rigorous instructional strategies occur to a greater extent in all core subjects at ECHS than in the comprehensive schools attended by control students (Edmunds et al., 2013).

Thus, the results of this study indicate that at ECHS, students experienced a mix of traditional and rigorous student-centered instructional methods. Students who experienced this instruction in college preparatory mathematics classes, starting with Algebra 1 in the 9th grade, outperformed control students in grades 9-11, with the impact of the model on underprepared students greater than on prepared students. While we can't claim any causal effects of instruction, these results suggest that as part of the ECHS model, a mix of student-centered and explicit instruction, with higher than typical levels of rigorous student-centered instruction (as indicated in student surveys), works (or at least does not hurt) for all, including underperforming students (Hiebert et. al., 2003; Weiss, Pasley, Smith, Banilower, & Heck, 2003; Williams et al., 2022). ECHS is a comprehensive reform model. It is purposefully designed to include multiple elements that are believed to work best together to ensure students' success in college preparatory and college level courses. As described here, a higher than typical level of rigorous student-centered instruction combined with rigorous course-taking produced beneficial outcomes in mathematics for a wide range of students, including both higher and lower achieving students.

Policy Implications

The results reported in this study clearly suggest that the set of policies and practices implemented as part of the comprehensive ECHS high school reform model provides substantial benefits for average and low achieving students' learning of mathematics. These results support prior research suggesting that the implementation of rigorous coursetaking for a wide range of students, including universal algebra policies for lower achieving students in or before 9th grade, can be successful under the right conditions. These conditions may include changes in instruction toward more student-centered methods, combined with rigorous approaches to content, as well as providing students with personalization and extensive academic support.

Districts considering the implementation of more rigorous course-taking for a wider range of students, including universal algebra in 8th or 9th grade, may find our results useful as they describe policies and conditions that support such implementation. Districts should consider supplementing changes in coursetaking with substantial changes in instruction and support provided to students to ensure their success in more rigorous courses. The ECHS reform model may provide some useful guidance to districts on how to approach this challenging task.

Limitations

This study reports on the successes of the ECHS reform model with a population of students largely underrepresented in college, including those unprepared for the 9th grade. At the same time, all students in the study, including those in the treatment and control groups, had to apply to early college, which created systematic differences with the general population of students. Students (or their parents) in our study were motivated enough to apply to ECHS, and in general, they were higher-achieving than the general population in the same districts (Edmunds et al., 2017). Several Investing in Innovation (i3) projects in multiple states are currently underway to expand the ECHS goals and principles in comprehensive schools. Evaluations of these initiatives will provide data on the effectiveness of this reform with the general student population.

Due to the limited number of observations and the observation protocol, which collected narrative notes rather than ratings of specific instructional features, the examination of instruction was purely descriptive. In this study, we could not detect any possible relationships between instructional features and outcomes or claim generalizability beyond the classrooms we observed.

Conclusions

This experimental study of the Early College High School reform model shows that the model is having statistically significant and substantively large impacts on student course-taking and success in mathematics college preparatory courses for both prepared and underprepared students. The impacts of this whole school reform are larger for underprepared students.

The analyses of classroom observations and interviews with mathematics teachers reveal that instruction in ECHS represents a mix of traditional approaches and rigorous student-centered instructional practices.

A number of ECHS' practices are likely to contribute to students' college readiness in mathematics: the course-taking policies, requiring all students to take college preparatory honors mathematics classes; the shift toward rigorous student-centered instruction in all classrooms; and the comprehensive academic and affective supports provided to students. By design, these practices are supposed to work in concert to ensure students' success. The ECHS model's success in improving mathematics outcomes for traditionally underachieving students provides additional support for the notion that, under the right conditions, underprepared students can successfully learn in universal algebra and in student-centered environments.

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References

Agodini, R., & Harris, B. (2016). How Teacher and Classroom Characteristics Moderate the Effects of Four Elementary Math Curricula. *The Elementary School Journal, 117*(2), 216-236.

Arshavsky, N., Edmunds, J. A., Bernstein, L., Unlu, F., Glennie, E., & Smith, A. (2014). *The Impact of Early College High Schools on Mathematics Teaching and Learning.* Paper presented at the National Council of Teachers of Mathematics Research Pre-session.

Arshavsky, N., Edmunds, J.A., Miller, L., Corritore, M. (2013). Success in the college prep mathematics pipeline: Impact of policies and practices employed by three high school reform models. *School Effectiveness and School Improvement: An International Journal of Research, Policy and Practice,* DOI: 10.1080/09243453.2013.846917.

Baker, S., Gersten, R. & Lee, D.S. (2002). A synthesis of empirical research on teaching mathematics to low-achieving students. *The Elementary School Journal, 103* (1), 51-73.

Balfanz, R., Legters, N., & Jordan, W. (2004). *Catching Up: Impact of the Talent Development Ninth Grade Instructional Interventions in Reading and Mathematics in High-Poverty High Schools.* Report 69: Center for Research on the Education of Students Placed at Risk CRESPAR.

Berger, A., Turk-Bicakci, L., Garet, M., Song, M., Knudson, J., Haxton, C., et al. (2013). *Early College, early success: Early College High School Initiative impact study*. Washington, DC: American Institutes of Research & SRI International.

Boaler, J. (2006). Urban success: A multidimensional mathematics approach with equitable outcomes. *Phi Delta Kappan, 87* (5), 364-369.

Carnevale, A. P., Jayasundera, T. & Gulish, A. (2016). *America's Divided Recovery: College Haves and Have-Nots.* Washington, DC: Georgetown University Center on Education and the Workforce.

Clements, Ken & Bishop, Alan & Keitel, Christine & Kilpatrick, Jeremy & Leung, Frederick. (2013). Third International Handbook on Mathematics Education. 10.1007/978-94-009-1465-0_1.

Conley, D. T., Drummond, K. V., de Gonzalez, A., Rooseboom, J., & Stout, O. (2011). *Reaching the Goal: The Applicability and Importance of the Common Core State Standards to College and Career Readiness:* Educational Policy Improvement Center.

Creswell, J. W., Plano Clark, V. L., Gutmann, M. L., & Hanson, W. E. (2003). Advanced mixed methods research designs. In A. Tashakkori & C. Teddlie (Eds.), *Handbook of mixed methods in social and behavioral research* (pp. 209-240). Thousand Oaks, CA: SAGE Publications.

Domina, T., McEachin, A., Penner, A., & Penner, E. (2015). Aiming High and Falling Short: California's Eighth-Grade Algebra-for-All Effort. *Educational Evaluation and Policy Analysis, 37*(3), 275-295.

Durwood, C., Krone, E., & Mazzeo, C. (2010). *Are Two Algebra Classes Better Than One? The Effects of Double-Dose Instruction in Chicago. Policy Brief* (No. 978-0-9845-0762-7): Consortium on Chicago School Research.

Edmunds, J. A., Bernstein, L., Glennie, E., Willse, J., Arshavsky, N., Unlu, F., et al. (2010). Preparing Students for College: The Implementation and Impact of the Early College High School Model. *Peabody Journal of Education, 85*(3), 348-364.

Edmunds, J.A., Bernstein, L., Unlu, F., Glennie, E., Willse, J., Smith, A. & Arshavsky, N. (2012). Expanding the start of the college pipeline: Ninth grade findings from an experimental study of the impact of the early college high school model. *Journal of Research on Educational Effectiveness, 5*(2), 136-159.

Edmunds, J.; Bernstein, L.; Glennie, E.; Willse, J.; Arshavsky, N.; Unlu, F.; Bartz, D.; Silberman, T.; Scales, W.D. & Dallas, A. (2011a). Preparing students for college: the implementation and impact of the Early College High School model. *Peabody Journal of Education, 85,* 348-364.

Edmunds, J. A., Bernstein, L., Unlu, F., Glennie, E., Arshavsky, N., Smith, A. (2011b). *Keeping students in school: Impact of a high school reform model on students' enrollment and progression in school.* Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, LA.

Edmunds, J. A., Bernstein, L., Unlu, F., Glennie, E., Smith, A., Arshavsky, N. (2011c). *The impact of the Early College High School Model on core 9th and 10th grade outcomes.* Paper presented at the Annual Meeting of the Society for Research on Educational Effectiveness, Washington, DC.

Edmunds, J.A., Unlu, F., Furey, J., Glennie, E., & Arshavsky, N. (2020). What happens when you combine high school and college? The impact of the early college model on postsecondary performance and completion. *Educational Evaluation and Policy Analysis, 42* (2), 257-278. https://doi.org/10.3102/0162373720912249

Edmunds, J. A., Unlu, F., Glennie, E., Bernstein, L., Fesler, L., Furey, J., & Arshavsky, N. (2017). Smoothing the transition to postsecondary education: The impact of the early college model. *Journal of Research on Educational Effectiveness, 10* (2), 297-325.

Edmunds, J. A., Unlu, F., Phillips, B., Glennie, E. J., & Mulhern, C. (2024). The Impact of Early Colleges on Postsecondary Performance and Completion. AERA Open, 10. https://doi.org/10.1177/23328584241290772

Edmunds, J.A.; Willse, J.; Arshavsky, N.; Dallas, A. (2013). Mandated engagement: the impact of early college high schools. *Teachers College Record, 115*:7.

Finkelstein, N. D., & Fong, A. B. (2008). *Course-taking patterns and preparation for postsecondary education in California's public university systems among minority youth.* (Issues & Answers Report, REL 2008–No. 035). Washington, DC: U.S. Department of Education, Institute of Education Sciences, National Center for Education Evaluation and Regional Assistance, Regional Educational Laboratory West.

Gamoran, A., & Hannigan, E. C. (2000). Algebra for everyone? Benefits of college preparatory mathematics for students with diverse abilities in early secondary school. *Educational Evaluation and Policy Analysis, 22*, 241–254. doi:10.3102/01623737022003241

Ham, S., & Walker, E. (1999). *Getting to the Right Algebra: The Equity 2000 Initiative in Milwaukee Public Schools.* MDRC Working Papers.

Hess, K. (2023). Rigor by Design, Not Chance: Deeper Thinking Through Actionable Instruction and Assessment. ASCD.

Hess, K., Gong B., Bayerl K. (2014). *Ready for College and Career?: Achieving the Common Core Standards and Beyond through Deeper, Student-Centered Learning.* Retrieved from http://www.nmefoundation.org/global/featured-research/homepage/ready-for-college-and-career.

Hiebert, J., Gallimore, R., Garnier, H., Givvin, K. B., Hollingsworth, H., Jacobs, J., Chui, A. M.-Y., Wearne, D., Smith, M., Kersting, N., Manaster, A., Tseng, E., Etterbeek, W., Manaster, C., Gonzales, P., & Stigler, J. W. (2003). Understanding and improving mathematics teaching: Highlights from the TIMSS 1999 Video Study. *Phi Delta Kappan, 84* (10),768-775.

Hollis, S. and F. Campbell (1999). What is meant by intention to treat analyses? Survey of published randomised controlled trials. *British Medical Journal, 319*: 670-674.

Ikemoto, G. S., Steele, J. L., & Pane, J. F. (2016). Poor Implementation of Learner-Centered Practices: A Cautionary Tale. *Teachers College Record, 118*(13).

Institute of Education Sciences (2005, December). *Key Items to Get Right When Conducting a Randomized Controlled Trial in Education.*

Jobs for the Future, (n.d., a). *Common Instructional Framework*. Retrieved from http://www.jff.org/services/early-college-design-services/common-instructional-framework

Jobs for the Future, (n.d., b). *Putting Students at the Center: A reference Guide.* Retrieved from http://www.studentsatthecenter.org/sites/scl.dl-dev.com/files/field_attach_file/NMEF_sclreframeweb.pdf

Kamin, D. C. (2016). The Common Core State Standards for Mathematics and College Readiness. *The Mathematics Educator, 25*, 52-70.

Kane, T. J., & Staiger, D. O. (2012). *Gathering Feedback for Teaching: Combining High-Quality Observations with Student Surveys and Achievement Gains.* Research Paper. MET Project. Bill & Melinda Gates Foundation.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why Minimal Guidance during Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-

Based, Experiential, and Inquiry-Based Teaching. *Educational Psychologist, 41*(2), 75-86.

Kroesbergen, E.H., Van Luit, J.E.H., and Maas, C.J.M. (2004). Effectiveness of explicit and constructivist mathematics instruction for low-achieving students in the Netherlands. *The Elementary School Journal, 104* (3), 233-251.

Le, V.N, Lockwood, J.R., Stecher, B.M., Hamilton, L.S., & Martinez, J.F. (2009). A longitudinal investigation of the relationship between teachers' self-reports of reform-oriented instruction and mathematics and science achievement. *Educational Evaluation and Policy Analysis, 31* (3), 200-220.

Lee, V E., & Bryk, A. S. (1989). A multilevel model of the social distribution of high school achievement. *Sociology of Education, 62*(2), 172-192.

Liang, J.H., P. E. Heckman, & Abedi, J. (2012). What Do the California Standards Test Results Reveal about the Movement toward Eighth-Grade Algebra for All? *Educational Evaluation and Policy Analysis 34*(3): 328-343.

Litke, E. (2019). The Nature and Quality of Algebra Instruction: Using a Content-Focused Observation Tool as a Lens for Understanding and Improving Instructional Practice. Cognition and Instruction, 38(1), 57–86. doi.org/10.1080/07370008.2019.1616740

Loveless, T. (2008). *The misplaced math student: Lost in eighth-grade algebra.* Washington, DC: Brookings Institution, Brown Center on Education Policy. Retrieved from http://www.brookings.edu/~/media/files/rc/reports/2008/0922_education_loveless/0922_education_loveless.pdf

Lynch, K., Hill, H. C., Gonzalez, K., & Pollard, C. (2019). Strengthening STEM Instruction in Schools: Learning From Research. *Policy Insights from the Behavioral and Brain Sciences, 6*(2), 236–242. https://doi.org/10.1177/2372732219864385

Marzano, R. J., and Toth, M. D. (2014). *Teaching for Rigor: A Call for a Critical Instructional Shift.* Learning Sciences Marzano Center: 1-4. Retrieved from http://www.marzanocenter.com/files/Teaching-for-Rigor-20140318.pdf

McCaffrey, D.F., Hamilton, L.S., Stecher, B.M., Klein, S.P., Bugliari, D. and Robyn, A. (2001). Interactions among instructional practices, curriculum, and student achievement: The case of standards-based high school mathematics. *Journal for Research in Mathematics Education, 32* (5), 493-517.

McCormick, N. & Lucas, M. (2011). Exploring mathematics college readiness in the United States. *Current Issues in Education, 14*(1). Retrieved from http://cie.asu.edu/ojs/index.php/cieatasu/article/view/680

National Center for Educational Achievement. (2009). *Core Practices in Math and Science: An Investigation of Consistently Higher Performing Schools in Five States.* Austin, TX: National Center for Educational Achievement.

National Governors Association Center for Best Practices & Council of Chief State School Officers. (2010). *Common Core State Standards for Mathematics.* Washington, DC.

National Mathematics Advisory Panel. (2008). *Foundations for success: The final report of the National Mathematics Advisory Panel*, U.S. Department of Education: Washington, DC.

Nomi, T. (2012). The Unintended Consequences of an Algebra-for-All Policy on High-Skill Students: Effects on Instructional Organization and Students' Academic Outcomes. *Educational Evaluation and Policy Analysis 34*(4): 489-505.

Nomi, T., & Allensworth, E. (2009). "Double-Dose" Algebra as an Alternative Strategy to Remediation: Effects on Students' Academic Outcomes. *Journal of Research on Educational Effectiveness, 2*(2), 111-148.

Nomi, T., & Allensworth, E. M. (2013). Sorting and Supporting: Why Double-Dose Algebra Led to Better Test Scores but More Course Failures. *American Educational Research Journal, 50*(4), 756-788.

Nomi, T., Raudenbush, S. W., & Society for Research on Educational, E. (2014). *Algebra for All: The Effect of Algebra Coursework and Classroom Peer Academic Composition on Low-Achieving Students*: Society for Research on Educational Effectiveness.

Nomi, T., Raudenbush, S. W., & Smith, J. J. (2021). Effects of double-dose algebra on college persistence and degree attainment. Proceedings of the National Academy of Sciences, 118(27), e2019030118.

Nord, C., Roey, S., Perkins, R., Lyons, M., Lemanski, N., Brown, J., & Schuknecht, J. (2011). *The nation's report card: America's high school graduates* (NCES 2011–462). Washington, DC: U.S. Department of Education, National Center for Education Statistics.

North Carolina New Schools (n.d., a). *Design principles for innovative high schools.* Retrieved from https://www.duplinschools.net/cms/lib01/NC01001360/Centricity/Domain/22/DesignPrincipleOverview_DuplinVersion_August2013.pdf

North Carolina New Schools (n.d., b). *Common Instructional Framewor.* Retrieved from http://www.huskyacademy.com/uploads/2/1/9/9/21994574/cif_introductionpacket-jan2012.pdf

Oakes, J. (1990). *Multiplying inequalities: The effects of race, social class, and tracking on opportunities to learn mathematics and science.* Santa Monica, CA: Rand Publishing.

Pane, J. F., McCaffrey, D. F., Slaughter, M. E., Steele, J. L., & Ikemoto, G. S. (2010). An Experiment to Evaluate the Efficacy of Cognitive Tutor Geometry. *Journal of Research on Educational Effectiveness, 3*(3), 254-281.

Rampey, B. D., Dion, G. S., & Donahue, P. L. (2008). *The nation's report card: Trends in academic progress in reading and mathematics.* Washington, DC: National Center for Education Statistics. Retrieved from http://eric.ed.gov/PDFS/ED505083.pdf

Rickles, J. H. (2013). Examining Heterogeneity in the Effect of Taking Algebra in Eighth Grade. *The Journal of Educational Research, 106*(4), 251-268.

Riordan, J.E. & Noyce, P.E. (2001). The impact of two standards-based mathematics curricula on student achievement in Massachusetts. *Journal for Research in Mathematics Education, 32* (4), 368-398.

Slavin, R.E., Lake, C., & Groff, C. (2009). Effective programs in middle and high school mathematics: A best-evidence synthesis. *Review of Educational Research, 79* (2), 839-911.

Smith, J. B. (1996). Does an Extra Year Make Any Difference? The Impact of Early Access to Algebra on Long-Term Gains in Mathematics Attainment. *Educational Evaluation and Policy Analysis, 18*(2), 141-153.

Stein, M. K., J. H. Kaufman, Sherman, M. & Hillen, A.F. (2011). Algebra: A Challenge at the Crossroads of Policy and Practice. *Review of Educational Research 81*(4): 453-492.

Timperley, H., Wilson, A., Barrar, H., & Fung, I. (2007). Teacher professional learning and development: Best evidence synthesis iteration (BES). Auckland, New Zealand:

University of Auckland. Retrieved from http://educationcounts.edcentre.govt.nz/goto/BES

The Education Alliance. (2006). *Closing the Achievement Gap: Best Practices in Teaching Mathematics.* Charleston, WV: The Education Alliance.

Walston, J., & McCarroll, J. (2010). *Eighth-grade algebra: Findings form the eighth grade round of the Early Childhood Longitudinal Study, Kindergarten Class of 1998–99* (NCES-2010–016). Washington, DC: U.S. Department of Education. Retrieved from http://nces.ed.gov/pubs2010/2010016.pdf

Walters, K., Smith, J. B., Leinwand, S., Surr, W., Stein, A., & Bailey, P. (2014). *An Up-Close Look at Student-Centered Math Teaching: A Study of Highly Regarded High School Teachers and Their Students.* American Institutes for Research.

Weiss, I. R., & Pasley, J. D. (2006). Scaling up instructional improvement through teacher professional development: Insights from the local systemic change initiative. Philadelphia: Consortium for Policy Research in Education (CPRE) Policy Briefs.

Weiss, I. R., Pasley, J. D., Smith, P. S., Banilower, E. R., & Heck, D. J. (2003). *Highlights report, looking inside the classroom: A study of K—12 mathematics and science education in the United States.* Chapel Hill, NC: Horizon Research, Inc.

What Works Clearinghouse (nd). *Effectiveness of Saxon Math mathematics curricula in middle grades.* Retrieved from http://ies.ed.gov/ncee/wwc/interventionreport.aspx?sid=448

Williams, R., Citkowicz, M., Miller, D. I., Lindsay, J., & Walters, K. (2022). Heterogeneity in Mathematics Intervention Effects: Evidence from a Meta-Analysis of 191 Randomized Experiments. Journal of Research on Educational Effectiveness, 15(3), 584–634. https://doi.org/10.1080/19345747.2021.2009072

Williams, T., Haertel, E., Kirst, M. W., Levin, J., Rosin, M., Perry, M., & Webman, B. (2011). *Improving middle grades math performance: A closer look at district and school policies and practices, course placements, and student outcomes in California.* Mountain View, CA: EdSource. Retrieved from http://www.edsource .org/assets/files/studies/mg-math/study11-mg-math-full.pdf

Appendix A: Classroom Observation Protocol

Learn and Earn Early College High School Research Study

Classroom Observation Protocol: Academic Year 2009–2010

Observer/Interviewer:________ ECHS Name:_________________

Observation date: ____________ Time Start: ________ End: ______

Teacher name:

Teacher Gender: Male_______ Female_________

Teacher Ethnicity: _____ American Indian or Alaskan Native

_____ Asian

_____ Hispanic or Latino

_____ Black or African American

_____ Native Hawaiian or Other Pacific Islander

_____ White

Grade Levels of students: __________________Course Title:__________________________

Students: Number of Males ________ Number of Females _________

Classroom Race/Ethnicity: % Minorities ___________

Overall rating of student engagement in meaningful academic activities: Please make marks on the graph to represent the different involvement levels of all of students. (Ex. You make 3 dots for 80% are engaged 80% of the time, 10% are engaged 100% of the time and 10% are not engaged at all).

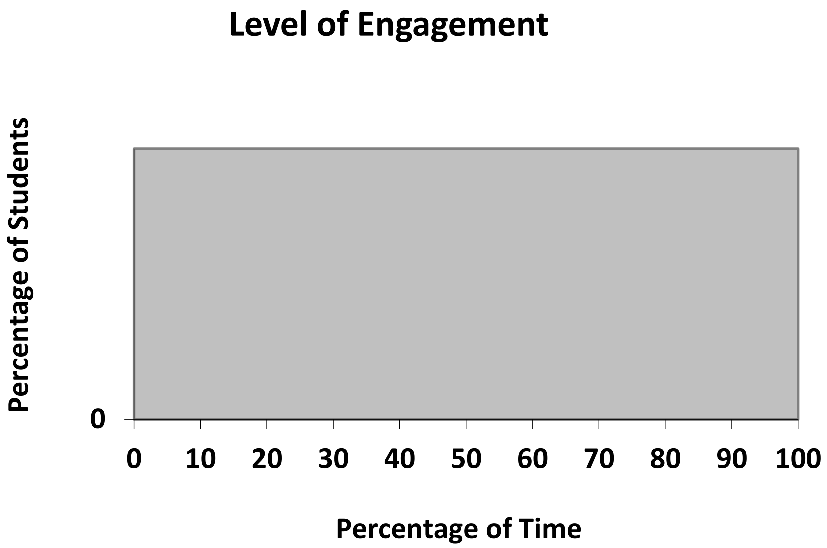

Diagram the classroom:

According to the teacher, the purpose of the lesson was:

As you are observing the classroom, please keep a running record of classroom activities. Specific things to watch for and describe (these are also listed on the attached sheets if you prefer to record them there):

Student Work:

- Description of what students are actually doing (not just what the teacher has assigned them to do)
- The content they are working with
- Engagement in higher order thinking
- Collaboration with other students and nature of that collaboration
- Engagement in "elaborated communication" (explaining thinking, writing, presentations, etc.)

Lesson Content:

- Links to SCOS
- Inclusion of specific facts/terminology of the discipline
- Extent to which lesson allows students to apply facts/terminology to complex problems

Lesson Instruction:

- Description of what the teacher is doing
- Incorporation of higher order thinking skills in questioning
- Incorporation of technology (if relevant)

Assessment:

- Use of any assessment strategies

- Any indications of teacher adjusting instruction because of informal assessment

Personalization:

- Indications of student being known by the teacher
- Ways in which the teacher connects with the students
- Examples of teacher-student relationships

Appendix B: Observation Coding Guide

Table B1. Observation Coding Guide

Code	Description for activities, lasting at least 10 min, to which the code should be assigned
Collaborative group work	Students are observed working together on tasks in groups of two or more.
Student communication	Students are observed engaged in writing or oral communication with each other and/or with a teacher.
Rigorous instruction	Students solve complex tasks with high cognitive demand. Students do mathematical investigations. Students engage in higher order thinking such as analyzing, summarizing, generalizing, evaluating, predicting, etc. Teacher encourages students to reason mathematically either by asking questions, or providing tasks or guidelines requiring reasoning. Students are observed engaged in mathematical reasoning.
Collecting evidence of student understanding	As a formative assessment strategy, teacher evaluates current student knowledge and understanding using various means such as questioning, brief quizzes or exit tickets, listening to students as they discuss assignments in groups, looking at student work, etc.
Explicit instruction	Teacher explicitly presents content to students, including concepts, representations, procedures, facts, solutions to

	problems, answering students' questions with explanations. Teacher provides clear models and multiple examples for problem solving followed by an extensive practice with similar problems, by students demonstrating solutions out load and receiving feedback on their solutions.