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Improving Students' College Math Readiness: A Review of the Evidence on Postsecondary Interventions and Reforms

A CAPSEE Working Paper

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July 2013

The author gratefully acknowledges the important feedback on an earlier draft of this paper from Uri Treisman of the University of Texas at Austin. Christina Chhin and Hiromi Ono of the Institute of Education Sciences and Shanna Smith Jaggars and Thomas Bailey of the Community College Research Center also provided helpful guidance and feedback throughout the project. The author also thanks Florence Ran of the Community College Research Center for assistance with Appendix B. The research reported here was supported by the Institute of Education Sciences, U.S. Department of Education, through Grant R305C110011 to Teachers College, Columbia University. The opinions expressed are those of the author and do not represent views of the Institute or the U.S. Department of Education.

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Abstract

This paper reviews current research on the effectiveness of interventions and reforms that seek to improve the math preparedness and success of high school students entering college. Based on gaps in the research knowledge, it also provides recommendations for further inquiry in particular areas. The studies reviewed here are selected from research conducted by the Community College Research Center (CCRC) and the National Center for Postsecondary Research (NCPR), from searches of the Education Full Text database for peer-reviewed articles, and from searches of Google Scholar for high-quality reports. The two key criteria for inclusion in the review are that (1) the study in question focuses on (a) an early assessment program in math; (b) a math bridge, boot camp, or brush-up; (c) a reform of developmental math; or (d) improvements to math instruction; and that (2) at least one of the study's outcomes is related to changes in math or college performance. To evaluate the evidence, I report on each study's design and findings. I also calculate each intervention's effect size and categorize the effect size to compare impacts across the studies under review.

Overall, the evidence is limited, but some of the interventions and reforms appear promising. The evidence on early assessment is minimal. The evidence on bridges, boot camps, and brush-ups suggests that short-term programs may only have short-term impacts. The evidence on different models of developmental reform varies depending on the reform model. For dominant models, it is positive (for compression models), insignificant (for learning communities), or negative (for modularization). For less prevalent models, it is positive (for mainstreaming) or needs further research (for statistics pathways). In terms of innovations that are strictly pedagogical, the strongest positive evidence is found for using structured forms of student collaboration and for building conceptual understanding through the use of multiple representations when teaching and solving problems. The evidence on computer-mediated instruction in the developmental math classroom is very mixed, with some studies finding positive effects and others finding negative effects.

Table of Contents

1. Introduction **1**
Four Strategies for Addressing Academic Underpreparedness in Math 3
Purpose and Method of This Review 4

2. Strategy One: Intervening During High School With Early Assessment **6**
Overview of Early Assessment 6
Evidence on Early Assessment 6
Directions for Research on Early Assessment 9

3. Strategy Two: Intervening Pre-Matriculation With Bridges, Boot Camps, and Brush-Ups **12**
Overview of Bridges, Boot Camps, and Brush-Ups 12
Evidence on Bridges, Boot Camps, and Brush-Ups 13
Directions for Research on Bridges, Boot Camps, and Brush-Ups 16

4. Strategy Three: Reforming Developmental Math **18**
Overview of Developmental Math Reforms 18
Evidence on Developmental Math Reforms 22
Directions for Research on Developmental Math Reforms 29

5. Strategy Four: Improving Math Instruction **31**
Evidence on Improving Math Instruction 31
Directions for Research on Improving Math Instruction 35

6. Conclusion **38**

References **40**

Appendix A: Search Strategy and Inclusion Criteria **50**

Appendix B: Summary of Studies **51**

1. Introduction

A major challenge facing many of today's students as they pursue a postsecondary degree is their lack of academic preparedness for college-level coursework and, in particular, for college-level math. Nationally, almost half of the 2003–04 cohort who enrolled in college directly after graduating from high school took at least one remedial course in college, and remedial course-taking is much higher at two-year colleges than at four-year colleges (see Table 1). Examining referral to remediation at community colleges by subject, Bailey, Jeong, and Cho (2010) found higher remediation rates in math: 59 percent of the community college students in their sample were referred to developmental math, compared to 33 percent who were referred to developmental reading.[1]

Table 1. Number of Remedial Courses Taken Among Students Who Graduated From High School in 2003 and Enrolled in College in 2003–04, by College Type

	Number of Remedial Courses Taken				
College Type	0 (%)	1 (%)	2 (%)	3+ (%)	Total (%)
Four-year	65.4	17.7	8.3	8.6	100
Two-year	32.1	20.7	16.0	31.2	100
Less-than-two-year	57.5	10.6	9.9	22.0	100
Total	52.6	18.6	11.3	17.5	100

Source: Author generated NCES QuickStats table using U.S. Department of Education, National Center for Education Statistics, BPS:2009 Beginning Postsecondary Students data. BPS: 2009 is transcript-level data for the 2003–04 cohort, tracked to 2009.

Entering college underprepared in math has a number of consequences. First, it poses an obstacle to completing a college-level math course, which can be a struggle for beginning postsecondary students, regardless of their initial course placement in college. Transcript data on the 2003–04 cohort reveal how students are faring in math across two-year and four-year colleges (U.S. Department of Education, 2012). Over a six-year period, 21 percent of the students who started at a four-year college never completed a college math course, either because they took no math or took only a remedial math course; 44 percent completed an introductory college math course as their highest math course; and 35 percent completed an advanced college math course (for example, pre-calculus). Among students who started at a two-year college, over a six-year period, 51 percent never completed a college math course, 40 percent completed an introductory college math course as their highest math course, and only 9 percent completed an

[1] The data used for this study was from more than 250,000 first-time, credential seeking students who began their enrollment in fall 2003 to fall 2004 at one of 57 colleges participating in the Achieving the Dream initiative. The sample more closely represents an urban, low-income, and minority student population than do community colleges in the country as a whole (Bailey, Jeong, & Cho, 2010, p. 258).

advanced college math course. College math completion is particularly low among community college students assigned to remediation: Only about 20 percent of community college students referred to developmental math ever complete a college-level math course (Bailey et al., 2010). Furthermore, there is evidence that college math success varies by student background. At the California community colleges, Asian and White students have significantly higher pass rates in college math than African American and Latino students (EdSource, 2012).

Academic underpreparedness in math not only poses an obstacle to college math success but also can have an impact on an individual's overall well-being if it hinders college progression and completion. The gap in earnings between high school and college graduates has been rising since the 1970s, and beyond their economic returns, college degrees are connected to many other positive outcomes, including higher levels of civic participation, healthier lifestyles, greater job satisfaction, and economic, educational, and health benefits that are passed down to one's children (Baum, Ma, & Payea, 2010). Leaving school without basic math skills can have far-reaching consequences: Quantitative literacy, which includes competency in the arithmetic and algebraic applications that are taught in high school or developmental math, has a strongly predictive relationship with a young adult's probability of employment and can explain much of the wage gap between African American and White young adults (Rivera-Batiz, 1992).

Finally, math underpreparedness also impacts the number of college students who are able to pursue Science, Technology, Engineering, and Math (STEM) degree programs that require advanced college-level math. The Executive Office of the President (2012) has called for increasing the number of students majoring in a STEM field in order to strengthen U.S. science and technology industries. Yet every year, large numbers of STEM-bound students fail to persist in their program (U.S. Department of Education, 2012). Between 2003 and 2009, approximately 28 percent of four-year and 20 percent of two-year college students began college as STEM majors. Less than half of these students persisted in a STEM major: 20 percent of four-year and 37 percent of two-year college STEM majors left college, and 28 percent of four-year and 33 percent of two-year college STEM majors switched to a non-STEM major. An important factor related to STEM attrition is preparation for college math: STEM leavers tended to take no math or remedial math in their first year in college, while STEM completers tended to start in college-level math.

Improving the college math readiness of high school students entering college may contribute to decreased remediation rates and increased rates of college persistence and degree completion helping to improve individuals' lifetime earnings and overall welfare. It may also bolster the quality of the workforce, particularly in science and technology fields—thereby helping to improve the nation's economy.

Four Strategies for Addressing Academic Underpreparedness in Math

Students enter college underprepared in math for a number of reasons—some did not take enough math in high school; some did not take the math they need for their college degree program; some did not master the math they took in high school; and/or some forgot the math they learned in high school (Fike & Fike, 2012). Additionally, students may feel frustrated or may struggle in their first math course in college because college placement exams are imperfect indicators of academic readiness; the exams misplace some students who are prepared for college math coursework into math remediation and misplace others who need additional support with basic math concepts into college-level coursework (Scott-Clayton, Crosta, & Belfield, 2012).

The underlying reasons for high rates of math remediation and college math failure thus necessitate a variety of reforms and interventions for improving students' readiness for college math as well as for measuring incoming college students' math skills. This review focuses on the interventions and reforms that postsecondary institutions currently employ to address academic underpreparedness in math and to foster college math success. These interventions and reforms fall under one of four different strategies: the first two (early assessment; bridges, boot camps, and brush-ups) seek to help high school students avoid math remediation before they begin their first semester at college so that they may enter college prepared for the first math course in their degree program, the third encompasses reforms to developmental math, and the fourth comprises improvements to math instruction in developmental and college math classrooms. Below, I briefly introduce the four strategies, each of which will be discussed in more detail later in the paper.

Strategy One: Intervening During High School With Early Assessment

The first strategy is the early assessment of high school students using college placement tests. The purpose of early assessment is to provide students an early indication of their level of college readiness based on the entry-level standards at their local four-year or community college (Barnett & Hughes, 2010). High school students who place into remediation then have time to work on their reading, writing, and math skills in order to avoid remediation once they enroll at college.

Strategy Two: Intervening Pre-Matriculation With Bridges, Boot Camps, and Brush-Ups

A second strategy is to intervene after high school students graduate but before they matriculate by providing short-term interventions. These bridge programs, boot camps, and brush-ups are designed to improve incoming college students' math skills and help them place into college-level math, usually college algebra or statistics, or, for STEM students, the first college math course in their program, usually pre-calculus or calculus (Kallison & Stader, 2012; Sherer & Grunow, 2010). The interventions typically take place on college campuses, occur during the summer, and are targeted at students who took the placement exam in high school or at the start of the summer and who placed into remedial math (or into a math class below the college math required for their STEM degree program). Individuals then participate in an intensive course for a short amount of time before the start of the semester and then retest to attempt to place into college-level math (or the first college math course in their program).

Strategy Three: Reforming Developmental Math

A third strategy is to reform developmental math in an effort to improve the outcomes of students who enroll in these courses. The traditional developmental education system may have high rates of course failure and student attrition because of its long sequence structure and misalignment between developmental and college-level standards and curriculum (Jaggars & Hodara, 2013). Reforms to developmental math attempt to address these weaknesses by shortening the sequence and/or aligning the curriculum to include the skills students need to be successful in the first college math course in their degree program.

Strategy Four: Improving Math Instruction

A fourth strategy is to focus on teaching and learning in the math classroom. This strategy overlaps in some ways with Strategy Three, given that some reforms of the developmental math sequence structure and curriculum may result in changes to instruction or explicitly include instructional reform. However, this strategy focuses exclusively on changes to pedagogy inside the math classroom. I focus on math instruction in postsecondary math classrooms in general (including both the developmental and college level), given that some students who enroll directly in college math are underprepared as well and also struggle to succeed.

Purpose and Method of This Review

The purpose of this review is twofold. First, it synthesizes the research on the effectiveness of interventions and reforms that seek to improve the math preparedness and success of high school students entering college. Second, it provides recommendations for future research and inquiry in this area. The studies reviewed here are selected from three main sources: research from the Community College Research Center (CCRC) and the National Center for Postsecondary Research (NCPR), searches of the Education Full Text database for peer-reviewed articles, and searches of Google Scholar for high-quality reports. The two key criteria for inclusion in the review are that (1) the study focuses on (a) an early assessment program in math; (b) a math bridge, boot camp, or brush-up; (c) a reform of developmental math; or (d) improvements to math instruction; and that (2) at least one of the study's outcomes is related to changes in math or college performance (e.g., employs measures of math learning, college math enrollment, or course pass rates, but not self-reported measures such as student satisfaction or math anxiety). Appendix A includes more details on the inclusion criteria and search strategy.

To evaluate the evidence, I report on each study's design and findings. I classify studies according to three types of study methods indicated in Table 2. The strongest evidence is from randomized control trial (RCT) and quasi-experimental design (QED) studies because of their use of a comparison group that can explain what would have happened if the treatment students had not received the intervention. Descriptive studies provide inconclusive evidence because it is not possible to attribute any observed outcomes to the intervention, as it is unknown if the outcomes would have been similar, better, or worse in the absence of the treatment. In addition to identifying the design of the reviewed studies, I calculate their effect sizes and effect categories, which allows for standardized measures of impact and the size of the impact across different types of interventions. Most of the very rigorous studies reviewed here, the RCT and QED studies, find trivial to small positive effects of the intervention or reform on students' academic outcomes.[2] For details on all the studies in this review, see the table in Appendix B, which provides a summary of each study's findings, the effect size and/or effect category of the findings, and indicates if the design used non-equivalent treatment and control groups or no comparison group.

Table 2: Study Type

Method	Description
Randomized controlled trial (RCT)	Participants are assigned to treatment and comparison groups entirely by chance.
Quasi-experimental design (QED)	Participants are not assigned to treatment and comparison groups by chance, but reasonable attempts are made to adjust for non-random assignment.
Descriptive	Study uses no comparison group or uses a comparison group with no adjustment for student differences.

This review is organized as follows. For each strategy, I first describe typical interventions and reforms, and provide some idea of the extent of their implementation across the nation; next, I summarize the extent and quality of the evidence on the effectiveness of the interventions and reforms; and finally, I outline directions for future research. A concluding section summarizes the gaps in the research and suggests questions for further exploration.

[2] A trivial effect size is equivalent to a zero to 0.20 standard deviation difference in means or zero to 10 percentage point difference in means, and a small effect size is equivalent to a 0.20 to 0.60 standard deviation difference in means or 10 to 30 percentage point difference in means (Hopkins, 2009).

2. Strategy One: Intervening During High School With Early Assessment

Overview of Early Assessment

Early assessment of high school students using college placement exams seems to be a fairly widespread practice across the United States (Hodara, Jaggars, & Karp, 2012). In most programs, colleges are minimally involved. While the colleges' placement tests are used to signal high school students' level of readiness for college-level coursework, high schools are left to decide what interventions, if any, to provide to students who are not deemed college-ready. For example, the University of Wisconsin has made a version of their placement exams available online for all Wisconsin high school students to take as sophomores, juniors, or seniors. The purpose of the early math placement tool program is twofold: to alert students to their level of readiness for college-level math in different degree programs at the University of Wisconsin, and to inform students about what kind of math they still need to take in high school to be college-ready in different degree programs (in order to encourage students to take more math in high school) (EMPT, n.d.).

It is less common for colleges and high schools to work together to design interventions for students who do not test as college-ready. Because early assessments are not typically paired with substantive academic interventions, Tierney and Garcia (2011), who have categorized college readiness efforts as "(a) academic, (b) information, and (c) motivational/social" (p. 107), regard early assessment as informational. However, some early assessment programs have an academic component as well. This section of the review discusses findings on the effectiveness of two well-regarded early assessment programs that have an academic component.

Evidence on Early Assessment

The evidence on the effectiveness of early assessment is minimal—only two studies report any quantitative findings. The first is a QED study of the California State University system's Early Assessment Program (CSU's EAP) (Howell, Kurlaender, & Grodsky, 2010), and the second is a descriptive study on a college readiness protocol in El Paso, Texas (Kerrigan & Slater, 2010). Both studies found that early assessment reduces the need for remediation, but impacts are trivial in size when standardized to allow for comparisons across studies (see Appendix B).

There are three components of CSU's EAP (Venezia & Voloch, 2012). The first component is early testing. CSU worked together with the California Department of Education and California State Board of Education to set standards of college readiness in reading, writing, and math. CSU and K-12 faculty then revised the California high school standardized test (CST) to include an optional section on the CST that assesses these standards, which are essentially CSU entrance standards. All juniors take the CST in English and, beginning in spring 2004, have the option to participate in the EAP through early testing. Students who take the CST can choose to complete an optional writing sample and reading test items that assess their readiness for college English at CSU. Only students who have completed Algebra II are eligible for the math CST, and they can complete optional math test items that assess their readiness for college math at CSU. Students' performance on the CSU-portion of the standardized test determines if they are prepared for college-level English and math at CSU. If they score above a college-ready cutoff, they can immediately enroll in college-level courses when they start at CSU. If they score below, they are directed to academic supports in their senior year, which encompass the second component of the EAP. CSU and high school faculty collaborated in the design of English courses, which cover both reading and writing skills, and math courses for students who need additional preparation, and CSU's diagnostic writing and math tests help students identify specific areas of weakness they should focus on. A third component of the EAP is professional development for high school teachers focused on aligning content and standards with postsecondary expectations. In 2008, EAP was expanded to students entering California community colleges, and some community colleges use student performance on the CSU portion of the CST to determine course placements.

Howell et al. (2010) evaluated the impact of the first component of CSU's EAP, early testing, focusing on a single campus, CSU-Sacramento, because it represents the average characteristics of students in the CSU system. They employed a quasi-experimental design using data on high school juniors in the 2001–02 to 2004-05 academic years and estimated the impact of the availability of EAP beginning in the 2003–04 academic year. The 2001 and 2002 juniors served as the control group, and the 2003 and 2004 juniors served as the treatment group. Controlling for student and high school characteristics, Howell et al. found that being a junior in the years EAP was available decreased students' probability of referral to remedial math at CSU by 3.7 percentage points. This estimate represents the intent-to-treat effect because participating in the EAP was optional. A second model estimated the treatment-on-treated effect, the impact of actual participation in the EAP, with a difference-in-differences design that interacts an indicator of being a junior in the years when the EAP was in effect with an indicator of participating in the EAP. Compared to students in previous years when EAP was not available and students in years when EAP was available who chose not to participate, the probability of being referred to remedial math at CSU for students who actually completed the optional test items on the CST decreased by 4.1 percentage points.[3]

These results are robust to alternative models that attempt to address potential confounding factors. One concern is that the model does not account for potential changing conditions for juniors from 2001 to 2004 that may be related to differences in their remediation rate. Howell et al. (2010) addressed this concern using propensity score matching to estimate the probability of referral to remediation of students who were juniors in the 2003 and 2004 years, when the EAP was available, who chose to participate in the EAP compared to similar juniors in

[3] The intent-to-treat effect on reducing the English remediation rate is insignificant (i.e., no different from zero). Actual EAP participation reduces the probability of being referred to English remediation by 6.1 percentage points.

those same years who chose not to participate. This model indicated that participation in the EAP reduced the probability of being referred to remedial math by 4.1 percentage points. A second concern is that the treatment on the treated estimate is upward biased because of unobservable differences between students who chose to participate in the EAP versus those who did not in the years it was available. The authors addressed this concern by estimating the intent-to-treat effect of the EAP on the probability of referral to remediation of students who attended high schools where almost all students participated in the EAP when it was available compared to students at those same high schools in the years before the EAP was available. This model indicated that being a junior in the years the EAP was available reduced students' probability of remediation by 3.9 percentage points.

The Howell et al. (2010) study provides suggestive evidence that the early testing component of CSU's EAP reduces the need for remediation, at least for students who attended CSU-Sacramento and were eligible for EAP because they completed Algebra II. However, no other quasi-experimental or experimental studies have been conducted on this intervention; thus the overall effect of CSU's EAP on California students' college readiness is unknown.

In addition to the California study, descriptive findings from El Paso illustrate an association between early assessment and a small drop in remediation rates. Representatives from El Paso Community College (EPCC), University of Texas at El Paso (UTEP), and area high schools created a "college readiness protocol" in 2005 (Kerrigan & Slater, 2010). During their junior or senior year, high school students in El Paso participate in the protocol, which consists of completing the joint admissions application to EPCC and UTEP, preparing for the ACCUPLACER placement exam, taking the ACCUPLACER, reviewing their scores, and, if necessary, refreshing their skills and retaking the exam. Summer bridge programs are available for students who place into remediation upon retaking the exam.

Almost three-quarters of incoming EPCC freshmen in 2007 participated in the protocol in high school, and EPCC institutional research found that 5 percent placed into college-ready math compared to 3 percent of the 2005 class, who had not been exposed to the protocol in high school (Kerrigan & Slater, 2010). Additionally, compared to the 2005 cohort, a much greater proportion of the 2007 cohort placed into the highest developmental math course, and a lower proportion placed into the lower levels. These findings do not account for differences in student-level characteristics, time-varying confounds, and endogenous sorting. For example, perhaps the 2007 cohort had better math skills, on average, than the 2005 cohort; perhaps high schools improved over time; or perhaps only the most motivated students took part in the college readiness protocol, inflating the true impact of early assessment. As a result, the association between early assessment in El Paso and the 2 percentage point increase in the proportion of college-ready students from 2005 to 2007 may be entirely explained by other factors. Furthermore, the fact that only 5 percent of incoming EPCC students placed into college math suggests that more far-reaching, systemic changes need to be considered to have a substantial impact on the college math readiness of El Paso high school students.

Directions for Research on Early Assessment

The two reviewed studies, as well as informal reports from other colleges that have conducted internal research on their remediation rates before and after implementation of early assessment (Hodara et al., 2012), suggest that early assessment may increase the number of high school students placing directly into college-level coursework. However, beyond this finding, we know little about early assessment and its impact on students. Therefore, rigorous research needs to be conducted to confirm if early assessment has a direct effect on reducing the remediation rate across different models, in different contexts, and with different types of students. A deeper look at the long-term impact of early assessment programs would also identify if they have more substantive benefits beyond reducing the remediation rate; in particular, in-depth studies might indicate whether programs enhance students' performance in math courses, college progression, persistence, and degree attainment.

Future research in this area should also explore the mechanisms underlying the impact of early testing. Howell et al. (2010) suggested two potential reasons for the impact of early testing on lowering students' probability of referral to remediation at CSU. One potential explanation is that high school juniors referred to remediation based on the CST were discouraged and, as a result, decided not to apply to CSU, thus lowering the remediation rate. However, Howell et al. found no evidence that students who did not test as college-ready on the CST were less likely to apply to CSU. Thus, Howell et al. inferred an alternative explanation: that juniors referred to remediation based on the CST took the necessary steps to improve their math skills, such as participating in an extra math class or academic support in their senior year, which helped them avoid remediation when they eventually enrolled at CSU.

Future research could also undertake an exploration of the role of early assessment in strengthening collaborations between secondary and postsecondary systems. One hypothesis is that early assessment programs have contributed to stronger relationships between secondary and postsecondary systems. Collaborative efforts between high school and college stakeholders working to implement early assessment programs have been documented in a number of states (California in Knudson, Zitzer-Comfort, Quirk, & Alexander, 2008; Spence, 2005; Spence, 2009; Venezia & Voloch, 2012; Florida in Bilsky, 2011; Burdman, 2011; Collins, 2009; New York in Venezia & Voloch, 2012; and Texas in Kerrigan & Slater, 2010).

For example, in 2007, after Florida joined the American Diploma Project, an initiative of Achieve, Inc. that works to help states raise academic standards, over 100 teachers and faculty from high schools, two-year colleges, and state universities from across the state met to discuss, decide on, and then draft entry-level college competencies in reading, writing, and math, called the Postsecondary Readiness Competencies (PRCs) (Bilsky, 2011). Then, in 2008, the Florida State Legislature passed legislation requiring all high school juniors to be assessed using a statewide college placement exam, and requiring high schools to provide students who place into remediation with remedial coursework prior to graduating from high school (Collins, 2009). The legislation prompted the faculty group who drafted the PRCs to reconvene and become heavily involved in the development of the new placement exam (Bilsky, 2011). The faculty group reviewed test items submitted by test vendors to assess which were the most closely aligned with the PRCs in order to help choose a test vendor to develop the new placement test, eventually called the Postsecondary Education Readiness Test (PERT). The faculty group also developed sample test items based on the PRCs for the PERT, and when the Common Core State Standards were released, the faculty group worked to align the PRCs with these standards and develop and review new test items for the PERT. In 2010, Florida began assessing high school juniors using the PERT and offering transitional courses to seniors who placed into remediation based on their PERT performance.[4]

However, an alternative hypothesis is that comprehensive early assessment programs, like the one in Florida, that involve an informational and academic component and are related to or result in efforts to align high school graduation and college entry standards are rare. Instead, qualitative studies suggest that while early assessment efforts are common, there is a lack of deeper collaboration between secondary and postsecondary institutions across the country. In a study of assessment and placement practices across 38 two-year colleges in seven states, Hodara et al. (2012) found a large number of early assessment efforts, but at only one college were faculty working with local high school administrators and teachers to create remedial interventions at the high school level for juniors who tested into remediation based on the college placement exam. Additionally, across the seven states, only Texas was involved in aligning high school graduation requirements with college-readiness standards (Hodara et al., 2012). In Grubb's (2013) study of 13 community colleges in California, only one college was found to be collaborating with a feeder high school to discuss ways to improve student readiness for college and to lower rates of remedial placement.

Partnerships between colleges and local high schools may become more common with the implementation of the Common Core State Standards (CCSS) (Barnett & Fay, 2013). For example, the implementation of the standards has spurred conversations in some postsecondary systems about aligning developmental education and/or introductory math and English curricula to the CCSS. In addition, early assessment may become more widespread. In the 2014–15 academic year, new assessments aligned with the Common Core States Standards will be administered to juniors to assess their level of college and career readiness in the 45 states that have adopted the standards. A cutoff score will be set that represents the minimum score to be considered college- and career-ready. If colleges honor this cutoff and allow students who score at or above it to enroll in college coursework without taking the college placement exams, then the administration of the new assessments will essentially represent a large-scale early assessment program. The scale of implementation poses a motivation for studying if and how early assessment affects students and presents opportunities for future research in this area.

[4] To date, there is no descriptive or quasi-experimental research on the impact of the administration of the Florida PERT and remedial interventions at the high school level on student outcomes.

To summarize, I recommend two general directions for research on early assessment:

1. **Rigorous evidence on the effects of early assessment and the mechanisms underlying its effects.** Research questions may include:
    a. What is the causal effect of signaling to high school students that they are not college-ready on their enrollment and performance in college math, and what are the long-term impacts on college outcomes, such as progression, persistence, and degree attainment?
    b. How do the effects vary across different contexts and models of early assessment, for example, when early assessment takes place at the sophomore, junior, or senior level; for students with different levels of initial math preparation in high school; and when early assessment programs are purely informational versus when they have an academic component and/or a motivational/social component?
    c. What is the effect of early assessment on participation in remedial interventions and other coursework choices at the high school level?
    d. For students who do not place as college-ready based on early assessment measures, how effective are remedial interventions at the high school level in improving their college math readiness, measured by math placement exam performance and enrollment and performance in college math? What features of remedial interventions at the high school level make them more or less effective?
2. **An understanding of the role early assessment plays in strengthening secondary and postsecondary partnerships.** Research questions may include:
    a. Do early assessment initiatives lead to greater collaboration between secondary and postsecondary institutions? What is the nature of this collaboration? Does early assessment lead to more remedial interventions at the high school level? Revisions of placement exams? More testing at high schools?

b. How will the implementation of the Common Core State Standards assessments impact early assessment programs and secondary and postsecondary partnerships generally?

3. Strategy Two: Intervening Pre-Matriculation With Bridges, Boot Camps, and Brush-Ups

Overview of Bridges, Boot Camps, and Brush-Ups

Bridges, boot camps, and brush-ups typically recruit high school students in their senior year who are on track for remediation or individuals who apply to college early and place into remediation. The programs consist of intensive basic skills courses that take place during the summer on college campuses (Sherer & Grunow, 2010). According to recent national scans of "math intensives" and developmental education innovations, bridges and boot camps are relatively common at colleges across the country (Edgecombe, Cormier, Bickerstaff, & Barragan, 2013; Sherer & Grunow, 2010). Community colleges also seem to be increasingly offering brush-up courses because they are low-cost and easy to scale up (Hodara et al., 2012).

Summer bridge programs have a long history in higher education (Strayhorn, 2011). Some bridge programs are for students who place into remediation while others are for students entering STEM programs who are not prepared for the first college math course in the STEM program, often pre-calculus or calculus. Many bridge programs are targeted to minorities and first-generation college students, and to individuals who have lower rates of persistence and completion than other college students and who are underrepresented in the STEM fields (Kallison & Stader, 2012; Lenaburg, Aguirre, Goodchild, & Kuhn, 2012; Stolle-McAllister, 2011; Walpole et al., 2008). Bridge programs are typically designed to improve students' math skills, as well as orient them to college culture, build their study skills, and provide them with an important network of support prior to enrolling. In this way, bridge programs attempt to impact students' college outcomes through multiple mechanisms: academic supports to help students start college in college-level coursework and non-academic supports intended to improve their persistence in college (Barnett et al., 2012).

Bridge programs and boot camps are very similar, and sometimes colleges use the term bridge program and boot camp interchangeably, but boot camps tend to be shorter in duration than bridge programs and primarily focus on building students' math skills and improving their performance on placement tests (Sherer & Grunow, 2010).

In contrast to bridge programs and boot camps, brush-up courses tend to last only a few hours and focus exclusively on placement test preparation, either for students testing for the first time or for students who initially tested into remediation and want to retest (Hodara et al., 2012). These courses are not necessarily designed to improve math skills; rather, they are focused on improving the accuracy of the student's test score and associated placement, by ensuring that the student is familiar with the exam and has the opportunity to refresh relevant pre-existing math knowledge. While bridge programs and some boot camps tend to have an informational, academic, and motivational or social component, brush-ups only have an academic component.

Evidence on Bridges, Boot Camps, and Brush-Ups

The evidence on bridges, boot camps, and brush-ups includes one RCT (Barnett et al., 2012) and a set of descriptive studies, many of which report institutional research (Gleason et al., 2010; Hodara et al., 2012; Kallison & Stader, 2012; Reisel, Jablonski, Hosseini, & Munson, 2012; Sherer & Grunow, 2010). Overall, these studies do not yield strong findings in favor of bridges, boot camps, and brush-ups: impacts are largely questionable given the lack of an equivalent comparison group and range in size and sign from trivially negative to moderately positive (see Appendix B).

Barnett et al. (2012) conducted a randomized experiment of developmental summer bridge programs offered to recent high school graduates at two open-admissions four-year colleges and six community colleges across the state of Texas. Students attended the summer bridge programs for three to six hours daily for four to five weeks. Although the programs at each college varied, they shared similar features: accelerated instruction in math, reading, and/or writing; academic support outside of class through individual tutoring and/or access to labs where tutors were available; a college knowledge component provided through advisors, mentors, and financial aid staff through a college success course or more informal presentations and workshops; and a stipend of $150 delivered at the start of the program to improve recruitment efforts and $250 delivered after completion of the program to encourage students to complete.

Study participants included those who placed into remediation, usually based on placement testing in their senior year in high school, and applied for admission to the summer bridge program in the summer of 2009 (Barnett et al., 2012). After agreeing to take part in the study, participants were randomly assigned to the summer bridge treatment group or the control group. Therefore, students in the treatment and control groups should be similar, on average, across observable characteristics, such as demographics and placement scores, and unobservable characteristics, such as motivation, and, therefore, any differences in their outcomes can be attributed to participation in the summer bridge program.

Students were followed for two years, and differences in outcomes reveal that the summer bridge programs had extremely modest impacts (Barnett et al., 2012). A higher proportion of students in the treatment group than the control group passed a college-level math course through the fall 2010, but by the spring 2011 there was no significant difference in the proportion of treatment group students (46.5 percent) and control students (43 percent) who passed college math.[5] Differences in persistence (i.e., total semesters registered over the two-year period), the number of college credits earned, and the number of college credits attempted of students in the treatment and control groups were also not statistically different from zero. The limitations of the study are that the researchers could not disentangle the effects of different components of the summer bridge program, and the results pertain to a specific group of students that placed into remediation but were motivated enough to sign up for a summer bridge program, and therefore the findings are not generalizable to all summer bridge programs and all types of students.

Importantly, Barnett et al. (2012) did not examine the program's impact on the most common outcome across studies of early assessment, bridges, boot camps, and brush-ups: course placement after the intervention. Instead, the researchers focused on the longer-term outcome of eventual college math completion. The statistically similar college math pass rates of the treatment and control groups signify that even if the Texas summer bridge program improved the college math placement of treatment students so that more treatment students placed into college math than control students, it had no impact on actually helping them pass college math. This suggests that programs that focus on improving placement test performance may not have a meaningful impact on improving students' performance in college math or long-term outcomes, such as persistence and progression.

Kallison and Stader (2012) also conducted a study on the Texas developmental summer bridge programs, but their study was descriptive and has limited internal validity. They examined gains in placement test scores among summer bridge participants who took a pretest and posttest. Only four institutions collected math test score data, and at these colleges there was no statistical difference in the math placement exam performance of students before and after participating in the summer bridge program.

Two descriptive studies (Gleason et al., 2010; Reisel et al., 2012) report on the outcomes of students in bridge programs at University of Alabama and University of Wisconsin-Milwaukee targeted to incoming STEM majors who placed below calculus; both universities identified an initial placement below calculus as a key predictor of STEM attrition. The bridge programs provided accelerated instruction in pre-calculus mathematical content, including college algebra and trigonometry, so that students did not delay enrollment in the calculus sequence. Both programs had similar features: they were residential (although in the first two years the University of Wisconsin program also allowed students to complete the program online from home); they lasted about one month; and students spent the mornings learning math content and the afternoons applying their math skills in real-world problem-solving activities. The University of Alabama program was voluntary for students who scored in a certain range below

[5] The same is true for treatment and control students referred to developmental reading: there were no significant differences in the proportion of students enrolling in college-level English.

the cutoff for placement into calculus, while the University of Wisconsin program was mandatory for students whose math ACT, high school grades, and class rank matched the profile of engineering students with the lowest graduation rates.

Gleason et al. (2010) found that although the Alabama students who took part in the summer bridge program, from 2005 to 2007, significantly increased their math placement scores upon completion of the program, not all students were able to place into calculus in the fall. Program students who placed into pre-calculus subjects performed significantly worse in pre-calculus courses than students with similar placement scores who placed directly into these courses, and there was no significant difference in the grades of program students who placed into calculus and control students who placed directly into calculus. The meaning of these results is unclear, because it is unknown how the program students would have fared in their first-semester math course in the absence of participating in the summer bridge program.[6] In terms of retention, 92 percent of students in the pilot program were still in a STEM degree program three years later, compared to 63 percent of STEM students who entered in the same year with similar placement test scores. Although this difference in STEM retention is quite large, it could be due entirely to the higher motivation of students who chose to participate in the summer bridge program.

The Reisel et al. (2012) study of the University of Wisconsin program did not employ a comparison group, and its purpose was primarily to track the relationship between features of the program and gains in students' math placement test scores upon completion of the program. Students in the residential program improved their math placement scores more than students in the online program (prompting the university to discontinue the online option in 2009); gains were trivial for students in the online program but of a moderate size for students in the residential program. In addition, in the morning session, students worked through individualized, self-paced math content using ALEKS (Assessment and Learning in Knowledge Spaces), a computer-adaptive, online assessment and learning program, and students with more ALEKS time-on-task had greater improvements in their placement test scores.

The remaining findings on boot camps and brush-ups are all descriptive reports based on colleges' internal research. Boot camps at EPCC in Texas, LaGuardia Community College in New York, Montgomery County Community College in Maryland, and Pasadena City College in California all report that a proportion of participants improved their placement exam performance and placed into a higher developmental math level or college-level math (Sherer & Grunow, 2010). At EPCC, specifically, students participating in the PREP boot camp take a diagnostic test on A+ Advancer, an online resource aligned to the ACCPUPLACER placement exam that creates an individualized test prep course for each student that targets his or her own areas of weakness. Students complete the individualized course in a lab where there are tutors

[6] For example, in the absence of the program, would program students fare even more poorly in calculus? If so, then the observed null result for calculus performance is in fact a positive result. On the other hand, if these students would have performed just as well in calculus without the program, then the null result indicates that the program was not helpful.

available. After they retake ACCUPLACER, they meet with a counselor to select courses and discuss their goals. From 2003 and 2008, between 52 to 66 percent of PREP participants placed at least one level higher in math (Sherer & Grunow, 2010). However, without a comparison group, it is unknown what the outcomes of these students would be in the absence of the treatment—for example, if the students had simply retested without participating in the boot camp.

Institutional research from a North Carolina college also finds a positive association between test preparation in a brush-up course and improvements in placement (Hodara et al., 2012). The North Carolina college created an online course for their reading, writing, and math placement exams, which students can access and complete from any computer at their convenience. The online course opens with a video of a student explaining the importance of the placement exams and the content of the review. For each subject, the course includes approximately one hour and twenty minutes of content: a diagnostic pretest, information on areas where the student is weak, instructional videos that cover the test content, a posttest, and additional resources to help students prepare for the test, such as PowerPoint presentations created by faculty and links to ACT online practice materials. The college found that from fall 2010 to spring 2011, among all students who took the review course before re-testing, 35 percent of students tested at least one level higher in the developmental math sequence and had similar or higher pass rates in the courses they retested into, compared with their counterparts who placed directly into the course. Currently, the state is working with a new placement test vendor to create similar, online brush-up courses that will be offered to incoming community college students statewide.

Directions for Research on Bridges, Boot Camps, and Brush-Ups

There is only one extant rigorous study on the impact of a summer program that attempts to improve the math placement and college performance of high school students who are on track for remediation. Barnett et al. (2012) found that the Texas developmental summer bridges programs had only short-term impacts on passing introductory college math, suggesting that short-term interventions are not sufficient to impact the educational outcomes of students in a meaningful way. In other words, summer programs should be one small component of a larger support framework for high school students as they transition from high school to college; other components might include early assessment, remedial interventions at the high school level, and supports that continue throughout a students' college career. Supporting students from their high school years into college could be an extremely resource-intensive, yet profoundly important endeavor. Therefore, understanding which program features have a long-term impact on students and are cost-effective is an important direction for research.

Some of this research is presently under way. Specifically, MDRC is conducting an evaluation of the "Getting Ready for Success" (GRS), a program in Tacoma, Washington, for low-income high school juniors, which builds on the lessons of the Texas developmental summer bridges evaluation (Sepanik, 2012). GRS students participate in an academic enrichment program before their senior year, work with college advisors and mentors during their senior year, and if they still need remedial support, take part in a summer bridge program after graduating from high school. During their first year in college, they continue to receive advising and mentoring, and receive incentives along the way that total to $3000 if they successfully complete all components of the program.

Another direction for future research is to better understand the causal effects of placement exam preparation, primarily offered through boot camps and brush-ups, on not only traditional indicators of placement test performance but also on math learning, as measured by grades in college math and perhaps a learning assessment, and subsequent college outcomes. Test preparation seems to help students who are underplaced and do not need remediation by allowing them to avoid unnecessary developmental coursework (Hodara et al., 2012). Test preparation may effectively prepare students for college math because it helps students refresh their math skills and/or relearn the math content. However, an alternative scenario is that improvements in placement exam performance do not necessarily mean students are prepared for college-level math, because students may be learning how to perform better on the exam but not learning the underlying content. If so, then students may need additional supports to perform well in the higher level course they place into after successfully participating in a boot camp or brush up.

Improvements in placement exam performance may also be weakly related to performance in college coursework because commercial placement exams comprise standardized content that is not necessarily aligned to the institution's introductory college-level math and English curricula (Hodara et al, 2012). The challenge in developing placement exams that more accurately reflect incoming students' readiness for introductory college coursework is creating an exam that directly tests the skills students need to be successful in their colleges' introductory math and English courses. Creating a customized exam may be a particular challenge for resource-constrained institutions and systems; commercial exams (for example, COMPASS and ACCUPLACER) are readily available and are perhaps less expensive than creating a customized exam. Yet, increasingly, higher education systems are addressing the misalignment between the content of the placement exam and introductory college English and math by developing their own customized exams that are aligned to the system's standards for readiness in introductory college English and math.[7] An interesting and useful research question would be to investigate if customized placement exams are more effective at predicting students' readiness for college than commercial exams.

To summarize, I recommend two general directions for research on bridges, boot camps, and brush-ups:

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[7] These are some systems and states that have a customized exam or are developing one: University of Wisconsin, City University of New York in English, Virginia Community College System, Florida, North Carolina Community College System (in development), and Texas (in development).

1. **An exploration of cost-effective features and models of bridges and boot camps that lead to long-term benefits for students.** Research questions may include:
    a. What academic and non-academic features of bridges and boot camps are most important in supporting students' college persistence and degree attainment?
    b. What is the optimal length of time that programs should support students as they transition from high school to college in order to yield cost-effective, long-term impacts?
2. **Causal evidence on the effects of test preparation delivered primarily through boot camps and brush-ups.** Research questions may include:
    a. What are the causal effects of test prep courses on enrollment and performance in college math courses as well as on performance on a math learning assessment?
    b. How do the effects differ if instruction is delivered face-to-face versus self-paced/online? How do the effects differ if features of the intervention include non-academic resources and staff support? How do the effects differ for customized versus commercial placement exams?

4. Strategy Three: Reforming Developmental Math

Overview of Developmental Math Reforms

The Status Quo

Typically, developmental math encompasses a sequence of courses that students are placed into based solely on their placement exam performance (Hodara et al., 2012). Sequences range in length, and some colleges may require more remedial math for students entering a STEM field compared to a liberal arts field. In a three-course sequence, for example, the lowest math course might cover arithmetic, the next course introductory algebra concepts, and the highest level course intermediate algebra, intended to prepare students for their first college-level math course, often College Algebra or Statistics.

The majority of developmental math students never complete their remedial requirements; some do not do so due to course failure, and others because they simply do not enroll in the next course in the sequence (Bailey et al., 2010). In general, these students have lower credit accrual, persistence, and graduation rates in comparison to their college-ready peers (Attewell et al., 2006; Jaggars & Hodara, 2011; Jenkins, Jaggars, Roksa, Zeidenberg, & Cho, 2009). Yet, it is difficult to infer if these poor outcomes are due to the ineffectiveness of developmental education or to the pre-existing characteristics of students who are in developmental education courses.

A growing body of rigorous research is attempting to identify the causal impact of developmental education on students' outcomes by disentangling the impact of student-level characteristics from the impact of developmental education (Bettinger & Long, 2009; Boatman & Long, 2010; Calcagno & Long, 2008; Dadgar, 2012; Hodara, 2012; Martorell & McFarlin, 2011; Scott-Clayton & Rodriguez, 2012). This research primarily relies upon regression discontinuity (RD) to address the non-random sorting of students into developmental and college-level courses. RD is used when an arbitrary cutoff (in this case, a score on a college placement exam) determines if individuals are assigned to an intervention or not (in this case, developmental or college courses). The underlying assumption of RD is that while placement exam performance may be positively related to educational outcomes, this relationship should be smooth (Imbens & Lemieux, 2008). For example, as placement score performance increases, we might see a smooth trend upward in the proportion of students enrolling in and passing college math. Additionally, the relationship between placement exam performance and student characteristics should be smooth. If these assumptions are met, then any discontinuity, or unnatural jump, in outcomes coincident with the score cutoff can be directly attributed to the only change that occurred at the cutoff—assignment to developmental or college math—rather than to student characteristics and other confounding factors, both observable and unobservable.

RD studies on developmental math at public four-year and community college systems across the county (Florida, New York, Virginia, and Texas) have largely found that developmental math has an insignificant or negative effect on the educational outcomes of students (Calcagno & Long, 2008; Dadgar, 2012; Martorell & McFarlin, 2011; Scott-Clayton & Rodriguez, 2012). Similar findings have emerged from studies of students assigned to lower levels versus higher levels of developmental math: around lower cutoffs, students tend to not benefit from more semesters of developmental math (Boatman & Long, 2010; Dadgar, 2012).

The consistency of these findings provides compelling support for their internal validity, but ultimately they do not identify exactly what is wrong with developmental education. The findings may be the result of misplacement: If the cutoffs are set too high or the placement exams are not accurate measures of math readiness, then some students placed into remediation may not actually need it. Or, perhaps students' developmental education placement is appropriate, but the long sequence length decelerates their progress into college coursework and they never catch up; perhaps the curriculum is not tied to what students need to know and be able to do to be successful in the college math for their own degree programs; and/or perhaps the courses' pedagogy does not effectively promote students' math learning and understanding. Across the country, colleges have sought to address each of these potential shortcomings of developmental education with a variety of reforms in an effort to improve students' developmental and college math success (Edgecombe et al., 2013b). These reforms, as well as those under strategy four, are focused primarily on academics although many have an explicit motivational or social component as well.

Alternatives to the Status Quo

In a recent scan of developmental education innovations that changed the developmental curricula, course structure, and/or pedagogy, Edgecombe et al. (2013b) found 52 community colleges engaged in developmental reform, with 41 innovations focused on math, 21 focused on English (combined reading and writing) and/or reading, and 4 that focused on math and English.[8] These reforms are aimed at changing the developmental course structure and/or curriculum, often in an effort to accelerate student progress through developmental education, and some attend to pedagogical changes as well. Edgecombe et al. identified how common each reform type was across the 52 colleges, and in the following subsections, I describe dominant and less prevalent models of reform and then present evidence on what is known about the effectiveness of these reforms.

Dominant models of developmental reform. Edgecombe et al. (2013b) found that the most common developmental innovations were compression (occurring at 17 colleges in their scan), modularization (occurring at 16 colleges), and linked courses or learning communities (occurring at 16 colleges). Compression and modularization are intended to accelerate student progress through developmental education by changing the traditional sequence structure and/or curriculum and offering only the content students need to succeed in college math (Edgecombe, 2011). Compression shortens the developmental sequence by combining two or more sequential developmental courses into a single semester. A compressed course does not require a change of curriculum if the number of contact hours remains the same, but if the number of contact hours decreases, then the content must be redesigned as well, often by eliminating redundancies in curriculum. Modularization divides the developmental curriculum into modules or single units that represent discrete math learning outcomes or competencies. Under this model, certain modules may be required for some degree programs but not others, and students may be allowed to move from one module to the next at their own pace using computer-mediated instruction. The course structure is not altered if the modules are offered within the existing semester-long

[8] The sample of colleges resulted from a detailed scan of developmental innovations occurring across the country, but do not represent all colleges innovating across the country. Edgecombe et al. (2013b) identified developmental education innovations through: phone conversations with reform leaders; online searches of professional associations and networks, conference proceedings, the RP Group website, and the Getting Past Go blog; the list of previous winners of the League for Innovation in the Community College's annual competition posted on their website; and recommendations from faculty, administrators, and other researchers familiar with developmental education reform landscape.

course, but it is substantially changed if colleges offer the modules as stand-alone, short courses, as the Virginia community colleges do under their developmental math redesign (Asera, 2011).

Linked courses or learning communities have a longer history at community colleges than models of acceleration. In a learning community, students enroll in two or more courses in the same semester together in order to create a supportive network of peers, shared learning experiences, and deeper connections to college (Tinto, 1997). The cohort experience is thought to improve student learning and persistence.

Less prevalent models of developmental reform. Less common developmental reforms include curricular redesign and mainstreaming (Edgecombe et al., 2013b). One curricular math reform that is growing in popularity revises the traditional algebra-based developmental math curriculum and shortens the sequence by creating a statistics-based developmental math sequence for non-STEM students. The Carnegie Foundation for the Advancement of Teaching set out to address the high rates of course failure and attrition among developmental math students by designing a developmental math pathway that is more closely aligned with the skills students need to be successful in college statistics, the college math course most liberal arts students take (Cullinane & Treisman, 2010). They first developed Statway, a year-long statistics pathway with one semester of developmental statistics and one semester of college statistics, that 30 community colleges across the country have adopted. More recently they developed a one-semester developmental quantitative literacy course, called Quantway, that eight community colleges have adopted.[9] Both pathways focus on teaching mathematics content that can be applied to solve everyday problems; this type of content lends itself to project-based learning and tends to be more closely aligned with the skills liberal arts students need to be successful in their degree programs and careers (Cullinane & Treisman, 2010; Merseth, 2011). The courses also seek to promote "productive persistence" (Merseth, 2011, p. 36), or non-academic behaviors associated with time management, motivation, and self-efficacy, through integrating college knowledge and other supports into the curriculum. In addition to the Carnegie Foundation–affiliated colleges, seven community colleges that are part of the California Acceleration Project have developed their own statistics pathways that are similar to Statway.[10]

Another acceleration model involves mainstreaming students who place into developmental math into college-level math courses and providing them with a supplemental support course (Edgecombe, 2011). Mainstreaming is more common in English than in math, and overall, a much less common form of acceleration compared to compression and modularization (Edgecombe et al., 2013b). Mainstreaming usually requires a change of placement test score policy to allow students who otherwise would have been required to take developmental education to enroll in college coursework. Additionally, faculty may develop or link a supplemental support course to their college-level courses designed specifically for

[9] See description on the Carnegie Foundation website: http://www.carnegiefoundation.org/statway
[10] See California Acceleration Project website: http://cap.3csn.org/developing-pilots/pre-statistics-courses/

students who would have been in developmental education but who are now in college coursework.

A second form of mainstreaming is integrating basic skills instruction into college-level courses (Perin, 2011). Examples of integration primarily come from certificate and associate occupational degree programs rather than liberal arts and sciences degree programs, and so usually involve integrating adult basic education curriculum into college-level occupational courses. For example, the Career Pathway Bridge programs at the Wisconsin technical colleges integrate different basic skills subjects into college-level courses for students seeking certificates in manufacturing, automotive fields, welding, baking, and nursing, as well as some associate degrees in similar fields (Valentine & Pagac, 2010).

Evidence on Developmental Math Reforms

Dominant Models of Developmental Reform

In this section, I summarize evidence from one RCT (Weissman, Butcher, Schneider, Teres, Collado, & Greenberg, 2011), three QED studies (Boatman, 2012; Edgecombe, Jaggars, Baker, & Bailey, 2013; Hodara & Jaggars, 2013), and three descriptive studies (Speckler, 2008; Squires, Faulkner, & Hite, 2009; Twigg, 2005). The research suggests promising, yet short-term impacts of compression, mild impacts of learning communities, and unclear impacts of modularization; all effect sizes are in the trivial to small size range (see Appendix B).

Compression. I summarize two QED studies here. Although the first study is not about a compression reform, it examines the same underlying treatment: shorter versus longer developmental math sequences. Hodara and Jaggars (2013) exploited a natural experiment in which community colleges in the same system, the City University of New York (CUNY) community college system, have the same standards of college readiness but different-length sequences, such that similar students are subject to longer or shorter sequences depending on where they attend college. At CUNY, during the time period of our study, all six community colleges referred students with a pre-algebra score below 27 to their lowest level of developmental math; thus in the analysis, Hodara and Jaggars focused on students who received the lowest score of 17 to a score of 26. Five colleges had a two-course sequence, such that students scoring below 27 on the pre-algebra exam started two levels below college-level math. One college had a three-course sequence, such that students scoring in the same range started three levels below college-level math. According to course descriptions in the college catalogs, the two-course sequences consisted of an arithmetic and beginning algebra course, while the three-course sequence comprised an arithmetic course and two algebra courses. Colleges with the two-course sequence spent an equal or greater number of contact hours on arithmetic concepts (3 to 6 credits, versus 3 credits in the longer sequence), but fewer contact hours on algebra concepts (4 to 6 credits, versus 8 credits in the longer sequence). The course descriptions also suggest that the highest-level course in the three-course sequence covered slightly more advanced material than the algebra courses in the shorter sequences.

To disentangle the impact of sequence length from student characteristics, Hodara and Jaggars (2013) compared the outcomes of similar students who started in the lowest-level of the three-course and two-course sequence using propensity score matching and cohort fixed effects so that only students within the same semester of entry were compared to each other. Among the matched sample of students, controlling for student-level covariates and semester of entry, students who started in a shorter sequence were 3.5 percentage points more likely to enroll in and 3 percentage points more likely to pass college math than their counterparts who started in the longer sequences. These estimates are significant at the 1 percent level. However, starting in a shorter sequence has no impact on three-year college credit accrual and only a small positive impact on credential completion. Controlling for student characteristics and cohort, those who started in a shorter sequence were 1 percentage point more likely to earn an associate degree over three years compared to their counterparts; this estimate is only significant at the 10 percent level.

The Community College of Denver (CCD) began to offer compressed versions of developmental courses in 2005, calling the program FastStart@CCD (Edgecombe et al., 2013a). FastStart encompasses a variety of course combinations but typically combines two sequential courses that would take two semesters to complete into one, single-semester course that maintains the same amount of contact hours. Edgecombe et al. (2013a) employed mixed methods to study the reform. Their qualitative research on FastStart found that the curriculum was also revised to allow for less review and more in-depth instruction on certain math topics, and that instructors changed their pedagogy in order to keep students engaged over longer stretches of course time. For example, rather than lecturing the entire time, math instructors reported integrating more group activities into their class. Another component of FastStart is that each participating student receives case management, which includes academic, career, and personal advising.

Edgecombe et al.'s (2013a) study examined the effects of two pairings: Fundamentals of Math and Pre-algebra (MAT 030/060, worth 5 credits) and Beginning Algebra and Intermediate Algebra (MAT 060/090, 7 credits). The analysis compared students who took a FastStart section between spring 2006 and spring 2008 to students who took a stand-alone version of the first course in the same pairing over the same time period. Both groups were tracked through fall 2010. Students who enrolled in the FastStart and non-FastStart sections were not equivalent: FastStart students were more likely to be female and Hispanic and less likely to be Black, less likely to have been referred to the lowest levels of developmental reading, more likely to be attending school full-time during the semester they enrolled in the paired course, and had slightly higher incomes. As a result, the authors used regression analysis to control for observable average differences.

Edgecombe et al. (2013a) found that, controlling for a wide range of student-level characteristics, there was no difference in the semester-to-semester persistence, three-year persistence, credits passed, and college credits passed among FastStart and non-FastStart developmental math students, but FastStart had a positive impact on passing the highest developmental math course (MAT090) and enrolling in and passing college math. In additional regressions, the authors controlled for the degree of case management the control group received, since less intensive case management was also available to students who did not participate in FastStart. The predicted proportion of FastStart students enrolling in college math was 38 percent, and the predicted proportion passing college math was 30 percent. This compares to 26 percent of non-FastStart students who received intensive case management enrolling and 14 percent passing; 14 percent of non-FastStart students who received light-touch case management enrolling and 9 percent passing; and 22 percent who received no case management enrolling and 16 percent passing.

Overall, both studies (Edgecombe et al., 2013a; Hodara & Jaggars, 2013) found a positive impact of shorter developmental math sequences on enrolling in and passing college math, but little indication that acceleration has long-term impacts on students. The main limitation of these studies is that possible unobservable differences between students who selected the colleges with shorter sequences at CUNY or the compressed math courses at CCD and students who selected the college with the longer sequence at CUNY or the traditional math courses at CCD were not accounted for in the analysis. As a result, the effects may be biased upward if students who selected into the treatment were more advantaged across unobservable characteristics or biased downward if students who selected into the treatment were more disadvantaged across unobservable characteristics.

A second concern of acceleration models, in general, is that compression may accelerate students' progress into college math, but those who enroll may not be as prepared as their counterparts who completed the traditional sequence. However, both studies (Edgecombe et al., 2013a; Hodara & Jaggars, 2013) examined conditional college math pass rates and found no difference in the college math pass rates of FastStart and non-FastStart students who enrolled in college math at CCD and students from shorter versus longer sequences who enrolled in college math at CUNY, indicating that the accelerated model did no harm to students' math learning.

Learning communities. Much of the literature on learning communities has been qualitative or has not focused on developmental math. The Learning Communities Demonstration project was a unique RCT conducted at six community colleges across the country; two of the colleges, Houston community college (HCC) and Queensborough community college (QCC), linked a developmental math course with a college-level or student success course (Weissman et al., 2011).

At QCC, new students who placed into either level of developmental math were eligible to enroll in a learning community that linked the lowest or highest developmental math course with developmental English or college-level English (fall 2007) or with a college-level introductory course (spring 2008 and beyond) (Weissman et al., 2011). Beginning in fall 2007 through spring 2009, 1,034 new, eligible students who were interested in joining a learning community at QCC were randomly assigned to a learning community or to a control group that had to take a regular developmental math course. A significantly higher proportion of students in the treatment group completed their developmental math course in the semester they participated in the learning community compared to students in control group (34 percent compared to 22 percent). But by the spring 2010 semester, students in the control group caught up, such that there was no difference in the developmental and college math completion rates of students in the treatment and control groups. The authors hypothesized that the sole impact of the QCC learning community may have been on encouraging students to not delay their math requirements.

At HCC, new students who placed into the lowest level of developmental math were eligible to enroll in a learning community that linked developmental math with a student success course (Weissman et al., 2011). From spring 2008 to fall 2009, 1,273 eligible students were randomly assigned to the treatment or control group. Findings at HCC are slightly more promising. A significantly higher proportion of students who participated in the learning communities passed the lowest level developmental math course in their program semester compared to students in the control group, and by spring 2010, there was still a significant different in treatment and control group completion rates (57.6 percent compared to 47.4 percent). A higher proportion of learning community students also attempted the highest level math course compared to control students, but a similar proportion of students in the treatment and control groups completed the highest level developmental math course.

At both colleges, there was no difference between the treatment and control groups in terms of college credit accumulation or persistence (Weissman et al., 2011). Thus, for the most part, the learning communities positively impacted students' developmental math pass rates but had no other impact. This is not to say that learning communities, in general, have no impact on students; the particular features and model of the learning community are vitally important. This same RCT found that the learning community model at Kingsborough Community College, which linked developmental or college English to two courses, an orientation course and an academic course, and which emphasized curricular integration, advising, and student supports, had a positive impact on the graduation rates of the treatment group.

Modularization. Modularization is a popular reform in developmental math, and it is often accompanied by computer-mediated instruction allowing students to work through the modules at their own pace (Twigg, 2005). Community colleges that redesign their developmental math courses so that the curriculum is delivered in discrete units through instructional software report improvements in developmental pass rates, college math enrollment and pass rates, and persistence for developmental math students (see, e.g., Speckler, 2008; Squires, Faulkner, & Hite, 2009; Twigg, 2005). However, this descriptive evidence does not utilize a comparison group; instead, it compares pass rates in the years before the redesign to pass rates in the years after the redesign is implemented, without adjusting for student differences pre- and post-course redesign and considering any time-varying factors, which could affect pass rates. For example, if enrollments increase in the years modularization is implemented, perhaps because an economic downturn propels more students into college, the average educational achievement of community college students' may increase regardless of the educational intervention they are exposed to. Or, if modularization leads to greater attrition and only the most motivated students remain, then average outcomes will seem higher under modularization.

Boatman (2012) employed a more rigorous QED in her study on the impact of modularization at Cleveland State Community College and Jackson State Community College in Tennessee, colleges that redesigned developmental math in 2007 with funding from the Fund for the Improvement of Postsecondary Education (FIPSE) through the U.S. Department of Education. Both colleges divided their developmental math curriculum into 12 modules, although not all modules were required of students in less math-intensive degree programs. Students worked through the modules at their own pace in an open computer lab with the assistance of an instructor and tutors.

In Tennessee, students place into developmental math, reading, and writing based on their ACT scores, and the state sets a cutoff score that sorts students into developmental or college coursework. This statewide consistency allowed Boatman (2012) to utilize a regression discontinuity design (RD) to identify the effects of modularizing developmental math. Because students do not perfectly comply with their developmental assignment, Boatman used an instrumental variable or "fuzzy" RD model, where the first stage predicts assignment to developmental education as function of ACT scores and the second stage estimates the effect of the predicted probability of developmental math enrollment on a set of outcomes. Boatman tested three different models, although I only discuss the most informative one in detail; in the others Boatman found null effects of moduralization.

Boatman (2012) compared the outcomes of students in developmental math versus college-level math prior to the redesign and under the redesign. At Cleveland State prior to the redesign, students who barely placed into developmental math (i.e., were very near the cutoff) were 15 percentage points more likely to persist to the second semester than their counterparts in college math, but after the courses were modularized, developmental math students were 36 percentage points less likely to persist to the second semester than before, or they were 21 percentage points less likely to persist than college math students. This negative effect of modularization on persistence is perhaps due to the self-paced nature of the courses: less direction and structure may be related to lower persistence. At Jackson State, there were no differences in the outcomes of students in developmental versus college math courses pre-redesign and post-redesign. Overall, the grant-funded redesign of developmental math had no impact or a negative impact, and students would have performed the same or better under the traditional sequence structure.

Less Prevalent Models of Developmental Reform

In this section, I summarize evidence from one descriptive study on a statistics pathway (Hern, 2012) and two QED studies on mainstreaming (Boatman, 2012; Zeidenberg, Cho, & Jenkins, 2010). The two QED studies found positive impacts of mainstreaming on student outcomes in the trivial to small effect size range (see Appendix B).

Curricular Redesign. To date, the only evidence on statistics pathways for non-STEM students has been descriptive, with colleges comparing college math enrollment and pass rates in the traditional developmental math sequence versus the new statistics pathway. For example, Hern (2012) reported that among students who took the traditional developmental algebra sequence at Los Medanos College (N = 1756), a two-year college, 33 percent who placed into intermediate algebra eventually passed a college math course, 17 percent who placed into elementary algebra eventually passed, and only 9 percent who placed into arithmetic eventually passed college math. In stark contrast, among students who took the new developmental statistics course (N = 119), 82 percent of students who would have had to take intermediate algebra based on their placement scores passed college statistics, 78 percent who would have had to take elementary algebra passed, and 38 percent who would have had to take arithmetic passed. Although these results are promising, students who took the statistics pathway make up a very small sample, and this comparison does not account for differences in students who selected the statistics pathway versus the traditional pathway.

Mainstreaming. Boatman's (2012) work in Tennessee also evaluated the effects of mainstreaming in math. Austin-Peay State University, a four-year college, took advantage of FIPSE to redesign developmental math by eliminating its two developmental math courses and creating two college-level math courses for students whose ACT scores placed them in developmental math. The college offered enhanced versions of Fundamentals of Mathematics and Elements of Statistics, two college-level math courses, linked to tutoring workshops for students who placed into developmental math (i.e., scored below the cutoff on the ACT that determines if students are college-ready in math or not). Boatman estimated the same RD models described previously (in the evaluation of modularization at Cleveland State and Jackson State community college) to evaluate mainstreaming at Austin-Peay. Unlike the effects of modularization, the effects of mainstreaming were generally positive.

Boatman (2012) found no difference in the outcomes of students who barely placed into developmental math (very near the cutoff) who enrolled in the new college math sections and students who barely placed into college math (very near the cutoff). This finding is quite promising because it means that students who were traditionally placed in developmental math can do just as well as their college math counterparts when they are instead placed into college math sections specifically designed with their needs in mind and provided tutoring supports.

Results were even more positive when Boatman (2012) compared the effects on students assigned to developmental math at Austin-Peay pre-redesign and post-redesign. Compared to students who barely placed into developmental math (very near the cutoff) before mainstreaming, students who barely placed into developmental math (very near the cutoff) who enrolled in the new college math courses passed more credits in their first semester, first year, and over two years, and they were more likely to persist from their first to second semester. Additionally, they were almost 7 percentage points more likely to persist to the next semester than students who just placed into college math, and they earned almost one more credit over two years than college math students. Boatman cautioned against interpreting the results as a sweeping endorsement of mainstreaming since one potential interpretation of the findings is that cutoff scores were too high and, as a result, students scoring below the cutoff that placed them into developmental math were actually college-ready in math. However, the alternative hypothesis is that thoughtfully designed acceleration programs, such as FastStart@CCD, the mainstreaming model at Austin-Peay, and the I-BEST model in Washington that I will discuss next, may improve the math learning and college success of students compared to traditional developmental math sequences.

The Washington State Board for Community and Technical Colleges (SBCTC) developed a mainstreaming model, called the Integrated Basic Education and Skills Training (I-BEST), intended to accelerate adult basic skills students' progress through the coursework required of their occupational certificate or associate degree program (Zeidenberg et al., 2010). In the I-BEST model, a basic skills instructor and an occupational instructor team-teach a college-level occupational or career-technical education (CTE) course and are in the classroom together for at least 50 percent of the instructional time (Wachen et al, 2012). When they are team-teaching, English and math basic skills content is integrated into the occupational curriculum, but the degree of integrated instruction varies widely across I-BEST programs. I-BEST programs also utilize contextualization, in which students focus on academic skills in support courses or in labs that are taught using applied examples from their occupational coursework.

Zeidenberg et al. (2010) evaluated the effects of I-BEST using multiple methods: propensity score matching (PSM) and difference-in-differences (DID). The authors did not report on the effects of integrating math, specifically, however; math and English content were often integrated together in the I-BEST courses, so the extent of the focus on math could not be determined. Using PSM, the authors matched basic skills students who enrolled in an I-BEST course to basic skills students who were in an occupational program, as evidenced by enrolling in at least one CTE course. The students who took an I-BEST course had higher college credit accumulation and degree completion, but these results may be subject to selection bias since PSM cannot account for the unobservable differences between basic skills students who chose to enroll in an I-BEST course versus a traditional CTE course.

The DID analysis provides more rigorous results because it can account for unobservable differences between the treatment and control groups (Zeidenberg et al., 2010). In the DID analysis, the authors used two groups of colleges: the treatment group included colleges that implemented I-BEST in the 2006–07 academic year, and the control group included colleges that implemented I-BEST in the 2007–08 academic year. The authors then estimated the effect of I-BEST enrollment from 2005–06 to 2006–07. Essentially, the DID estimate represents the increase in student outcomes from pre- to post-I-BEST implementation, while controlling for any other external changes that may have affected student outcomes during that period using similar colleges that implemented I-BEST in later years. Zeidenberg et al. found that basic skills students in occupational programs at schools where I-BEST was offered were 7.5 percentage points more likely to earn a certificate within three years (but no more likely to earn an associate degree) and almost 10 percentage points more likely to earn some college credits compared to similar students at colleges without I-BEST. It is important to recognize, however, that because I-BEST involves the integration of both math and English basic skills, the results of the PSM and DID analyses cannot be attributed to math alone.

Directions for Research on Developmental Math Reforms

Three directions for research on developmental math reforms emerge from this review. I discuss the first two here; the third direction for research concerns modularization and computer-mediated instruction, which I discuss in the fifth section under directions for research regarding improving math instruction.

First, in the area of acceleration, undertaking rigorous evaluations that address the mechanisms underlying acceleration may prove useful for practitioners thinking about the design of new accelerated math sequences. Four studies (Boatman, 2012; Edgecombe et al., 2013a; Hodara & Jaggars, 2013; Zeidenberg et al., 2010) have found positive effects of shorter developmental math sequences and mainstreaming developmental math students into college math classes. However, it is unclear how to ensure that acceleration models will have a lasting effect on the math learning and college progression of students.

One hypothesis is that structural changes to the developmental sequence may have limited effects, but the combination of structural, curricular, and pedagogical changes to a developmental math sequence as well as the provision of non-academic supports can impact the college success of students in long-lasting, meaningful ways. For example, a structural change, such as combining two developmental math courses into one, eliminates an opportunity for students to exit the sequence between semesters and, as a result, automatically boosts the number of students completing developmental math. However, also attending to curriculum and pedagogy may lead to a deeper impact when the accelerated model facilitates the delivery of more rigorous, engaging content and standards that help motivate students struggling with math and may thus better prepare them for college-level work (Koski & Levin, 1998).

A second area for future research is exploration of the implementation and impact of statistics pathways; Rutschow and Schnieder (2011) recommended the same direction for research in their review of what works in developmental education. A quasi-experimental or experimental evaluation of a statistics pathway at a college or set of colleges is warranted since there are not yet any RCT or QED studies of statistics pathways. Additionally, such a study might include a qualitative component that explores pedagogical innovations and non-academic supports within a statistics pathway and the professional development and growth tied to teaching in a statistics pathway compared to what is found in more traditional developmental math. Another important area of inquiry is student perspectives regarding how they choose the non-STEM statistics pathway over a more traditional developmental algebra pathway, how students feel the statistics pathway impacts their math learning and confidence, and the implications of their choices for their future academic and career goals.

In summary, I recommend two directions for research on developmental math reforms:

1. **An exploration of the mechanisms underlying different models of acceleration.**
    a. What are the comparative effects of developmental math acceleration models that employ: (1) only a course structure change, (2) both structural and curricular changes, (3) structural, curricular, and pedagogical changes, and (4) structural, curricular, pedagogical changes as well as additional academic and non-academic supports?
    b. Do models of acceleration have the same effect as simply lowering placement scores and allowing more students into college math?
2. **Quantitative and qualitative studies on statistics pathways.** Research questions may include:
    a. Compared to enrolling in a traditional developmental algebra sequence, what are the causal effects of enrolling in a remedial statistics pathway on non-STEM students' enrollment in and passing of college-level math, college progression, and degree completion? How do these results vary by gender, race, and other student demographics?
    b. How do faculty instruction and provision of non-academic supports compare in a developmental statistics versus algebra pathway?
    c. How do students choose to enroll in a statistics pathway, and what implications does this choice have for students who decide to switch majors later?
    d. What do students report are additional benefits (or drawbacks) of a statistics pathway compared to a developmental algebra pathway?

5. Strategy Four: Improving Math Instruction

There are no national studies that document the common features of math instruction in developmental and college math courses. Based on qualitative studies, however, typical developmental math pedagogy is thought to rely largely on procedural skill-building (Goldrick-Rab, 2007; Hammerman & Goldberg, 2003). For example, observational studies at thirteen community colleges in California found that mathematics instruction was characterized by "remedial pedagogy," i.e., review, lecture, independent seat-work, and math problems devoid of application to the real world (Grubb, 2013; Grubb & Worthen, 1999). Although traditional features of math instruction that emphasize procedural skills have been linked to better performance on standardized tests, and although much of the math that people encounter in their lives requires the ability to use algorithms to quickly and accurately solve computations, in order to truly understand mathematics, students need much more than procedural fluency (Hiebert & Grouws, 2007; Kilpatrick, Swafford, & Findell, 2001).

Therefore, an important component of improving students' college math readiness is improving math instruction in both the developmental and college-level classroom in order to support math learning and success. Kilpatrick et al. (2001) identified five interdependent strands of mathematical learning that instructional practices must address to build mathematical proficiency:

1. *conceptual understanding*—the understanding of why and when a mathematical idea is important or useful;
2. *procedural fluency*—the ability to use procedures in the right way and for the right purpose;
3. *strategic competence*—problem formulation and representation;
4. *adaptive reasoning*—logical reasoning about mathematical relationships; and
5. *productive disposition*—the belief that a sustained effort in learning mathematics will lead to greater understanding and benefit one's life.

This section reviews the evidence on forms of instruction that are thought to support components of mathematical learning beyond procedural fluency and that should thus develop mathematical proficiency more effectively than traditional instruction.

Evidence on Improving Math Instruction

Studies reviewed in this section draw primarily from a previous literature review I conducted on math instruction (Hodara, 2011). I also include studies from Perin's (2011) literature review of contextualization and studies from a search of more recent quantitative literature on college math instruction. Both of the literature reviews covered pedagogical innovations in secondary and postsecondary schools, but for the purpose of this review, I include only the studies from postsecondary math classrooms. Because of the large number of studies in this section (28), I only discuss the RCT and QED studies; see Appendix B for a list of all studies. The highest quality studies on improving math instruction at the postsecondary level have found positive effects of employing structured forms of student collaboration and using multiple representations to teach mathematics, with effect sizes ranging in the small to moderate range.[11]

Structured Student Collaboration

Two of the studies on using structured forms of student collaboration in developmental math used a fairly rigorous design and found small to moderate effects on students' course outcomes and/or math achievement (Dees, 1991; DePree, 1998), while the remaining five studies did not adequately adjust for pre-treatment differences between the treatment and control groups (Duncan & Dick, 2000; Hooker, 2010; Keynes & Olson, 2000; Norwood, 1995; Siadat, Musial, & Sagher, 2008). In the QED study by DePree (1998), students selected one of 50 sections of a developmental pre-algebra course, unaware that seven sections would utilize small-group instruction based on the Johnson and Johnson cooperative learning model and that six sections would be included in a control group and utilize the traditional lecture mode of instruction. The Johnson and Johnson cooperative learning model is characterized by face-to-face interaction, personal responsibility in working toward a shared goal, the use of interpersonal skills, and group processing through the exchange of feedback, explanations, and other information (Johnson, Johnson, & Smith, 1991). In structured cooperative learning situations with these elements, motivational, affective, and cognitive mechanisms are thought to lead to improvements in learning outcomes. In the cooperative learning sections, a significantly higher percentage of students completed the course than in the control sections (42 percent compared to 34 percent), and female and Latino students in the experimental sections reported significantly greater confidence in their mathematical ability than those in the control sections.

Dees (1991) randomized over 70 students in her developmental math course into four laboratory sections taught by graduate assistants: two that used structured, small-group instruction and two that used teacher-directed instruction with no group work. In the small-group instruction sections, particular individuals in groups of four to six students received only part of the instructions to a problem, and then students shared with their group the information they received. The group had to work together to understand the problem instructions and then solve the problem. At the end of the activity, one group member was randomly chosen to explain the group's solution, and the group's grade was based on this explanation, so group members had to

[11] It is interesting to note that many of instructional reforms have impacts that are of the same or greater size as programs and interventions discussed in the previous sections that require a substantial investment of resources. However, the outcomes in the instructional studies, which are typically related to math learning, and the outcomes in the other studies, which include placement test performance, enrolling and passing college math, and general college progression, are not necessarily comparable; the reforms may have different impacts on the long-term success of students.

collaborate to ensure everyone in the group understood the solution steps and final answer. Students in the cooperative learning lab consistently outperformed students in the control group on measures of math achievement that included teacher-made tests and a standardized final exam, with effect sizes ranging from 0.39 to 0.56 standard deviations.

Using Multiple Representations

The next set of studies covers math instructional strategies that emphasize conceptual learning, a fairly abstract concept that is represented in these studies by concrete activities in which the instructor teaches students to solve problems in different ways using multiple representations of math, such as using graphing calculators, drawing graphs, creating tables in Excel, and using traditional formulas (Chappell, 2006; Hollar & Norwood, 1999; O'Callaghan, 1998; Zawaiza & Gerber, 1993). These studies found small to large positive effects, and O'Callaghan (1998) and Chappell (2006) conducted fairly rigorous studies by adjusting for the pre-treatment differences of the treatment and control groups. However, the validity of the results in the O'Callaghan (1998) study are questionable because the outcome measure, an assessment of mathematical learning designed by the author, is aligned directly with the curriculum of the treatment classrooms (also taught by the author) and, as a result, is not a fair assessment of the kinds of procedural skills emphasized in the control group.

The highest quality study in this set, Chappell (2006), employed a number of methods to ensure that even though students self-selected into concept-based calculus and traditional calculus sections (unaware of the instructor or instructional method of each section), the faculty and students across both groups were comparable. In addition, frequent, unannounced classroom observations by faculty not directly involved in the study confirmed that in the concept-based sections, faculty taught students how to solve problems using numerical, graphical, and algebraic methods while constantly connecting new ideas to prior knowledge. In the control sections, faculty moved through the textbook teaching definitions and formulas in a linear manner. Students in the concept-based sections performed significantly better on the midterm and final exams and were better able to transfer their understanding to unfamiliar concepts. For example, on a final exam problem that had never been introduced in any of the classes, 88 percent of the students in the concept-based classrooms answered this question correctly, representing their answer in different ways (e.g., with an algebraic formula, graph, and/or numerically), and only 3 percent did not support their answer with an explanation. Only 54 percent of the students in the traditional sections answered this question correctly, with most of them providing textbook formulas or definitions to explain their answer and 31 percent not providing any explanation.

Emphasis on Metacognition

The next studies explore the impact of metacognitive strategies that promote an awareness of each student's own problem-solving and thought processes in developmental and college math (Abdalkhani & Menon, 1998; Porter, 1996; Schurter, 2002). The findings are mixed with moderate negative to small positive effect sizes. All three studies provide detailed descriptions of innovative ways in which to incorporate writing, self-reflection, and comprehension monitoring into math instruction, but, in addition to not adequately controlling for pre-treatment differences between the treatment and control groups, in two of the studies, the author was the instructor of the treatment classes, but not the control classes.

Contextualization

The following five studies on using application-based instruction or contextualization generally find positive effects of this mode of instruction with trivial to small positive effect sizes (Ellington, 2005a; Ellington, 2005b; Ganter & Jiroutek, 2000; Shore, Shore, & Boggs, 2004; Vasquez, 2004), but similar to the previous set, the studies have methodological drawbacks that call into question the validity of their findings. In Perin's (2011) extensive review of contextualization (i.e., the practice of embedding discipline-based content into basic skills instruction) in K-12, adult literacy, and developmental classrooms, the studies, mostly from English classrooms, generally found positive effects, suggesting that this is a promising means of supporting academically underprepared students. However, only one study in Perin's review (Shore et al., 2004) was conducted in the postsecondary math classroom, so there is little evidence on contextualization in this setting specifically.

Computer-Mediated Instruction

The final category, computer-mediated instruction, includes studies that assess the impact of developmental math courses in which students work through technology-delivered mathematics content at their own pace during some or all of classroom time, with the instructor providing some face-to-face interaction through offering individualized attention, delivering instruction, and/or providing technology support (Ashby, Sadera, & McNary, 2011; Aycaster, 2001; Garcia, 2003; Hagerty & Smith, 2005; Lovett, Meyer, & Thille, 2008; McClendon & McArdle, 2002; Taylor, 2008; Zavarella & Ignash, 2009; Zhu & Polianskaia, 2007). All of the studies in this category were conducted in classrooms in which the curriculum was not modularized, or divided into discrete units; studies of computer-mediated instruction in modularized classrooms were covered in the previous section. Additionally, I did not include studies that only assess the impact of fully online learning models in this category; a comprehensive review of online education at community colleges is covered in articles by Jaggars (2011, 2012), which generally find negative effects for fully online learning among community college students.

The set of studies on computer-mediated instruction is notable for the high degree of mixed results: three studies found small positive effects of computer-mediated instruction, one study found small negative to moderate positive effects, and five studies found trivial to small negative effects. Additionally, only two of the studies employed an equivalent comparison group, so the evidence is inconclusive on the effects of computer-mediated instruction on student outcomes.

The two studies with fairly rigorous designs both found positive effects of computer-mediated learning. Lovett et al. (2008) evaluated the effects of an accelerated Open Learning

Initiative (OLI) college statistics course at Carnegie Mellon University, in which students worked through interactive statistics activities delivered through computer software at their own pace and met with an instructor in a lab during a scheduled time. Lovett et al. (2008) randomized students to the eight-week OLI statistics course and a 15-week lecture-based course and found positive effects of the OLI course on students' final exam performance. However, while these findings suggest promising results for this model of math instruction, it is impossible to disentangle any effects of the OLI pedagogy (i.e., the particular computer software and the mix of instructor-directed and self-paced learning) from the effects of acceleration. In other words, the eight-week structure of the course may have contributed to differences in final exam outcomes either by motivating students or through another mechanism.

Finally, the study in this section that provides the most direct evidence of the effects of computer-mediated instruction used a quasi-experimental design to evaluate the use of ALEKS in college algebra (Hagerty & Smith, 2005). Students at a university in the Midwest self-selected into six algebra sections without knowing which courses were ALEKS-based and which were traditional, textbook-based courses. Each instructor taught both a treatment and control section offered on the same days (except for one instructor who only taught a control section because he was unfamiliar with ALEKS). The students in the ALEKS sections experienced small gains in algebra learning compared to students in traditional algebra course sections, as measured by a math assessment. However, the final results only include students who took both the pretest and the posttest, not accounting for the test scores of students who enrolled late or withdrew from the course, so differential attrition could have biased the results.

Directions for Research on Improving Math Instruction

There are two valuable general directions for future research on instruction in developmental and college-level math. First, modularization and computer-mediated instruction are common reforms and deserve deeper understanding; Rutschow and Schnieder (2011) also pointed out that technology-aided instruction is extremely popular in developmental education yet is under-researched.

Thus far, evidence from three sets of reviews on modularization and computer-mediated instruction points to a mix of results that provides no clear understanding of the effects of these reforms on students. First, the studies on computer-mediated instruction reviewed in this section found negative, positive, or null effects on student outcomes, although most studies suffer from methodological weaknesses, so the results are difficult to interpret. Second, many of the studies on modularization in the previous section found positive impacts but did not make use of an equivalent comparison group or any comparison group at all. In contrast, Boatman (2012) has presented the highest quality study on modularized developmental math and found negative impacts. However, it is impossible to assess if these effects were due to the modularization of the curriculum or the pedagogy, which includes the impact of the particular software, the self-paced nature of learning, and the degree of individualized attention from instructors. Third, studies from the state of Washington and Virginia on online learning find negative impacts of online learning in math courses on student learning and college progression (Xu & Jaggars, 2011a; Xu & Jaggars, 2011b). These negative effects may be due to a lack of instructor guidance and support, difficulties with the software, and/or a lack of structure compared to face-to-face courses (Jaggars, 2012). These same mechanisms underlying the negative impact of online learning may be present in self-paced, computer-mediated classrooms in developmental math. As a result, an important direction for research should be rigorous evaluations of modularization and computer-based instruction in developmental math that identify features of these instructional models that support students and improve their college math readiness and success.

A second direction for research concerns a general question about how to encourage the adoption and spread of effective pedagogies in developmental and college math classrooms. While there is still much to learn about how to teach math effectively in higher education, existing research, particularly from the K-12 setting, does point to some effective strategies, and yet there is qualitative evidence that developmental math instructors widely use "remedial pedagogy" (Grubb, 2013). An extension of this research area is to examine the efficacy and appropriateness of adopting math instructional strategies that are effective in one setting (such as the secondary or college-level math classroom) for another setting (such as the developmental math classroom). There are a number of rigorous studies from the K-12 setting that have found a positive impact of using structured forms of student collaboration on students' math learning (Hodara, 2011). Two studies from developmental math classrooms (Dees, 1991; DePree, 1998) suggest that different forms of student collaboration, designed specifically for college students, are also effective. Therefore, the evidence seems to suggest that research-based or thoughtfully designed forms of student collaboration are effective in many different settings. However, in terms of using multiple representations, all four studies are from the college-level math classroom. Thus, the question remains: If developmental math instructors adopted and adapted the approach used in the Chappell (2006) study for their own classroom, would they find the same positive effects of using multiple representations on students' math learning?

To summarize, I recommend two directions for research on developmental math reforms:

1. **Identifying the effects of modularization and computer-mediated instruction.** Research questions may include:
    a. What forms of computer-based learning support student math learning and college success? How do the effects of computer-based learning models vary depending on the degree of self-paced learning, teacher and student interaction, and student collaboration in the classroom?
    b. Do certain software programs lead to greater gains in student learning? If so, what are the specific instructional elements that seem to contribute to these gains?

c. To what extent are the effects of modularization on students' math learning and long-term outcomes due to curricular redesign (dividing the curriculum into discrete units) versus pedagogical changes (the use of instructional software to deliver curriculum)? To what extent are the effects due to the degree of teacher and student interaction and student collaboration in the classroom?

d. How do the effects of modularization and computer-mediated instruction vary for different types of students—for example, for students in developmental versus college math coursework?

2. **Exploring ways to improve math instruction in higher education through the adoption and adaptation of effective math instructional strategies.** Research questions may include:

   a. What can colleges do to encourage the adoption and adaptation of effective math instructional strategies in developmental and college math classrooms?

   b. What can developmental and college math instructors learn from effective math teaching at the secondary level, or what can developmental and college math instructors learn from each other? What instructional strategies that work for secondary math students in preparing them for college-level math would benefit students in developmental math or students struggling with college-level math? What instructional strategies that work for students with learning disabilities in math may be appropriate for students in developmental math or students struggling with college math?

6. Conclusion

This review has evaluated the extent and the quality of evidence on reforms intended to improve the college math readiness of students entering college. Early math assessment and bridges, boot camps, and brush-ups target students pre-matriculation in an attempt to increase rates of placement into college-level math during students' first semester in college. Reforms to developmental math seek to improve students' math success in developmental math coursework and increase the probability of entry and success in college-level math. Improving math instruction in postsecondary math classrooms is important for increasing students' math learning so that they can successfully complete developmental or college math coursework. Overall, some of these interventions and reforms appear promising, yet additional research is needed to answer questions that remain, including whether and how these interventions can have longer-term, more meaningful effects on students.

Specifically, the evidence on early assessment is minimal. Two studies, a QED and a descriptive study, suggest that early assessment reduces the remediation rate. However, effects are relatively trivial, and it is unclear if early assessment has any long-term impact on students' college success.

The evidence on bridges, boot camps, and brush-ups suggests that short-term programs may only have short-term effects. In the RCT of the Texas summer bridge program, Barnett et al. (2012) found a positive effect of the bridge program on passing college math in the short-term but found no differences in passing college math over the long term, in persistence, or in college credit accumulation. The remaining five descriptive studies also found short-term effects of bridges, boot camps, and brush-ups in terms of increasing the number of students placing into college math or higher developmental courses; however, they did not address any potential effects on performance in college math or other longer term outcomes.

The evidence on dominant models of developmental reform varies depending on the reform model. Research on compression is limited but positive and suggests that this reform is a promising means to accelerate developmental math students' progress into college math. The RCT on learning communities (Weissman et al., 2011) found that the math learning communities did not impact students' college math success, but effects for learning communities vary depending on their implementation, and it is possible that these particular programs were not well implemented. Finally, the QED study on modularization found that this reform had a negative effect on persistence and insignificant effects on all other outcomes. The negative effect of modularization may have been due to the self-paced, computer-mediated instructional model. The evidence on less prevalent developmental math reforms is positive (for mainstreaming) or inconclusive (for statistics pathways).

In terms of innovations that are strictly pedagogical, the strongest evidence is in favor of structured forms of student collaboration and of building conceptual understanding through the use of multiple representations when teaching and solving problems. The evidence on computer-mediated instruction in the developmental math classroom is very mixed, with some studies finding positive effects and others finding negative effects. Given the popularity of computer-mediated instruction in developmental math classrooms, an important area of research concerns how computer-mediated classrooms can effectively prepare students for college math and support their overall success.

Based on gaps in the existing relevant findings, I outline the following directions for additional research:

1. Carrying out additional rigorous research on the effects of early assessment and the mechanisms underlying its effects;
2. Building a better understanding of the role early assessment plays in strengthening secondary and postsecondary partnerships;
3. Identifying cost-effective features and models of bridges and boot camps that lead to long-term benefits for students;
4. Conducting causal research on the effects of test preparation delivered primarily through boot camps and brush-ups;
5. Investigating the mechanisms underlying different models of acceleration;
6. Conducting quantitative and qualitative studies on statistics pathways;
7. Identifying the effects of modularization and computer-mediated instruction; and
8. Exploring ways to improve math instruction in higher education through the adoption and adaptation of effective math instructional strategies.

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Appendix A: Search Strategy and Inclusion Criteria

Strategy	Inclusion Criteria
Strategy 1	1. CCRC reports: a. Hodara et al. (2012) b. Kerrigan & Slater (2010) 2. Education Full Text and Google Scholar search: a. Publication range from 2000 to the present b. Search terms: college AND early assessment program high school AND college AND (developmental OR remedial) AND (testing OR exams OR assessment) 3. Exclude article if there is no quantitative outcome related to math or college performance.
Strategy 2	1. NCPR Report: Barnett et al. (2012) 2. Education Full Text and Google Scholar search: a. Publication range from 2000 to the present b. Search terms: summer bridge college AND (bridge OR boot camp OR brush-up OR brush up) 3. Exclude article if there is no quantitative outcome related to math or college performance.
Strategy 3	1. NCPR/CCRC reports: a. Report on Scaling Innovation reforms (Edgecombe et al., 2013b) b. Evaluation of I-BEST (Zeidenberg et al. 2012) c. Evaluation of FastStart (Edgecombe et al., 2013) d. Evaluation of Tennessee course redesign (Boatman, 2012) e. Evaluation of learning communities (Weissman et al., 2011) 2. Recent literature not covered by above reviews using Education Full Text and Google Scholar searches: a. Publication range from 2011 to the present. b. Search terms: developmental math 3. Exclude article if there is no quantitative outcome related to math or college performance.
Strategy 4	1. CCRC reports: a. Math pedagogy literature review (Hodara, 2011) b. Contextualization literature review (Perin, 2011) 2. Recent literature not covered by above reviews using Education Full Text and Google Scholar searches: a. Publication range from 2011 to the present. b. Search terms: college math instruction 3. Exclude article if there is no quantitative outcome related to math or college performance.

Appendix B: Summary of Studies

Study	Summary of Findings	Effect Size[1]	Effect Category[2]	Non-Equivalent Comparison Group	No Comparison Group
Strategy One: Intervening During High School With Early Assessment					
Howell et al. (2010)	At California State University-Sacramento, participation in the Early Assessment Program (i.e., taking the optional CSU test items on the California standardized test as a high school junior) reduced the probability of placing into math remediation as a college freshman.	-0.037	Trivial negative		
Kerrigan & Slater (2010)	At El Paso Community College, a comprehensive college readiness protocol for high school students increased the proportion of students placing into college math and higher levels of developmental math.	N/A	Trivial positive	X	
Strategy Two: Intervening Pre-Matriculation With Bridges, Boot Camps, and Brush-Ups					
Bridges					
Barnett et al. (2012)	The Texas Developmental Summer Bridge Program had a positive impact on first college-level course completion in math and writing, but no significant effect on credit attainment or persistence.	-0.076 to 0.05	Trivial negative to trivial positive		
Kallison & Stader (2012)	The math placement scores of Texas Developmental Summer Bridge Program participants decreased at some colleges and increased at others, but gains/losses are not significant. (Effect size of 0.92 represents large gains in ACCUPLACER scores for six students at one college.)	-0.007 to 0.92	Trivial negative to moderate positive		X
Gleason et al. (2010)	Participants in the Engineering Math Advancement Program at University of Alabama increased their math placement scores and had higher retention than non-participant STEM students.	N/A	Trivial to moderate positive	X	
Reisel et al. (2012)	Participants in the summer bridge program at the University of Wisconsin-Milwaukee experienced gains in their placement scores, especially in the face-to-face model (compared to the online model).	0.05 to 1.04	Trivial to moderate positive		X

Study	Summary of Findings	Effect Size[1]	Effect Category[2]	Non-Equivalent Comparison Group	No Comparison Group
Boot camps					
Sherer & Grunow (2010)	The PREP program in El Paso Community College increased the proportion of students placing into higher levels of developmental math.	N/A	Small positive		X
Brush-ups					
Hodara et al. (2012)	At a North Carolina community college, about 35 percent of students who took the placement test review tested at least one level higher in developmental math.	N/A	Moderate positive		X
Strategy Three: Reforming Developmental Math					
Compression					
Hodara & Jaggars (2013)	At the City University of New York community colleges, enrolling in a shorter developmental math course sequence compared to a longer math sequence had a positive effect on enrolling in and passing college math, and had a small impact on degree attainment.	0.01 to 0.10	Trivial positive		
Edgecombe et al. (2013)	At the Community College of Denver, FastStart students in compressed math courses had higher gatekeeper math enrollment and pass rates than similar non-FastStart students.	N/A	Small positive		
Learning communities					
Weismann et al. (2011)	Learning communities at Queensborough and Houston community colleges led to more students passing developmental math courses in the program semester but had no other significant impacts.	0 to 0.17	Trivial positive		
Modularization					
Boatman (2012)	At Cleveland State and Jackson State community colleges, in comparison to the outcomes of students around the margin of the cutoff pre-redesign, after the implementation of modularization, students who placed into developmental math had lower rates of persistence. Otherwise there was no difference in outcomes.	N/A	Small negative to trivial positive		
Speckler (2008)	At 18 colleges, retention and pass rates, course enrollments, and/or grades were generally higher for students in sections that used MyMathLab or MathXL than in sections that used traditional (lecture) instruction.	N/A	Small to moderate positive	X	
Squires et al. (2009)	At Cleveland State Community College, after the introduction of modularization, course completion rates in developmental math and subsequent college-level math courses increased.	N/A	Small positive	X	

Study	Summary of Findings	Effect Size[1]	Effect Category[2]	Non-Equivalent Comparison Group	No Comparison Group
Twigg (2005)	Different outcomes were examined at 30 selected institutions, with in-depth case studies on 15 institutions. Colleges that modularized their math courses reported increases in retention, math learning, and course pass rates, and reported a decreased cost per student.	N/A	Small positive		X
Curricular redesign (statistics pathways)					
Hern (2012)	At Los Medanos College, students who took the accelerated statistics pathway had higher college math completion rates than students who took the traditional developmental algebra pathway.	N/A	Moderate positive	X	
Mainstreaming					
Boatman (2012)	At Austin-Peay State University, compared to the outcomes of students prior to the implementation of mainstreaming, students assigned to developmental math who enrolled in the new college math courses passed more credits and were more likely to persist from their first to second semester.	N/A	Trivial to small positive		
Zeidenberg et al. (2010)	Students in occupational programs at schools where I-BEST was offered were more likely to earn a certificate within three years (but no more likely to earn an associate degree) and more likely to earn some college credits compared to similar students at colleges without I-BEST.	N/A	Trivial to small positive		
Strategy Four: Improving Math Instruction					
Student collaboration					
Dees (1991)	Students randomized into cooperative learning sections performed significantly better on the algebra word problem and geometry proof-writing than students in the traditional sections.	0.39 to 0.56	Small positive		
DePree (1998)	A significantly higher percentage of students in the cooperative learning sections completed the course than students in the control sections, and Latino and female students in cooperative learning classes had positive gains in self-reported math confidence relative to the control group, but there were no differences in the achievement gains of treatment and control groups.	0.45 to 0.72	Small to moderate positive		
Duncan & Dick (2000)	The Math Excel students attained significantly higher grades than the non-Math Excel students, and students in the Math Excel Program outperformed their predicted grades, as determined by their SAT Math score, by half a grade point.	N/A	Moderate positive	X	
Hooker (2010)	Students in pre-algebra classes that used peer-led team leader (PLTL) workshops had higher persistence and completion rates than control group students.	N/A	Trivial to small positive	X	

Study	Summary of Findings	Effect Size[1]	Effect Category[2]	Non-Equivalent Comparison Group	No Comparison Group
Keynes & Olson (2000)	Students in the Calculus Initiative classrooms had higher GPAs, pass rates, and retention rates than students in traditional calculus.	N/A	Small positive	X	
Norwood (1995)	Compared to students who took developmental algebra in the semester when instructors used traditional methods, a higher proportion of students who took developmental algebra in the semester that the instructors used the learning model of cooperative learning completed their first college-level math course.	N/A	Small positive	X	
Siadat et al. (2008)	The Keystone Method involves daily assessment of students and use of cooperative learning groups. Students in the Keystone Method classes had higher final exam scores and persistence rates than students in traditional, control classes.	N/A	Small to large positive	X	
Using multiple representations					
Chappell (2006)	Students in the concept-based calculus sections scored significantly better on the midterm and final exams than students in the traditional sections, except for on the final procedural skill section.	0.34 to 0.64	Small to moderate positive		
Hollar & Norwood (1999)	Scores on the function test were higher for the graphing-approach group than for the control group, but there were no significant differences in terms of final exam scores (scores not reported).	1.02	Large positive	X	
O'Callaghan (1998)	The Computer-Intensive algebra students scored higher than students in the traditional algebra classrooms on the function test, and there were no significant differences in final exam performance (scores not reported).	0.86 to 1.07	Large positive		
Zawaiza & Gerber (1993)	Community college students with learning disabilities who received a schema-based intervention made greater gains on a word problem test than those who did not, and they performed at almost the same level as their math-competent peers.	0.27 to 1.11	Small to large positive	X	
Metacognitive strategies					
Abdalkhani & Menon (1998)	In earlier courses in which journal writing was not used in math, students had a mean score of 65 percent on quizzes, while students in the course that incorporated journal writing had a mean quiz score of 72 percent.	N/A	Trivial positive	X	
Porter (1996)	There were no differences in the number of procedural errors made by students in a college calculus course that used writing to learn math and students in a comparison course on a final exam, but students in the treatment group made more conceptual errors.	-0.63 to 0.09	Moderate negative to trivial positive	X	

Study	Summary of Findings	Effect Size[1]	Effect Category[2]	Non-Equivalent Comparison Group	No Comparison Group
Schurter (2002)	Students who received direct instruction in the use of comprehension monitoring or Polya's four-step problem-solving method performed better in mathematical problem solving than those who did not.	N/A	Small positive	X	
Application/Contextualization					
Ellington (2005a)	Students in modeling sections had higher levels of self-reported confidence, lower levels of anxiety, and lower withdrawal rates than students in traditional sections.	N/A	Trivial to small positive	X	
Ellington (2005b)	Students in modeling sections performed significantly better on an assessment and had higher pass rates than students in traditional sections.	0.41	Small positive	X	
Ganter & Jiroutek (2000)	Calculus sections that utilized long-term projects in the computer lab did not perform better than the control sections on the final exam. On the standardized exam the control group outperformed the treatment group.	N/A	Trivial negative	X	
Shore et al. (2004)	Allied health students who participated in a developmental math intervention using problem-based learning in which instruction was contextualized in a nursing topic (kidney function) showed greater gain than students in traditional instruction.	N/A	Trivial to small positive	X	
Vasquez (2004)	A greater percentage of students passed higher level math courses after the introduction of the Algorithmic Instructional Technique (AIT). AIT involves real-world problem-solving and content that integrates content relevant to students' lives.	N/A	Trivial to small positive		X
Computer-mediated instruction					
Ashby et al. (2011)	Students had higher developmental math pass rates in the face-to-face course compared to online course or blended course; students in the online course had higher developmental math pass rates than those in the blended course.	-0.30 to 0.54	Small negative to moderate positive	X	
Aycaster (2001)	The success rates in 15 developmental math courses were not related to the method of instruction (lecture or computer-aided instruction).	N/A	Trivial negative	X	
Garcia (2003)	Pre- to posttest mean ACCUPLACER scores increased for students in an elementary algebra class with learning style and attitude surveys, workshops, computer-based instruction, self-assessment, and supplemental instruction.	N/A	Small positive		X
Hagerty & Smith (2005)	The students using ALEKS had higher gains from pre- to posttest than the students in the traditional classrooms.	0.49	Small positive		

Study	Summary of Findings	Effect Size[1]	Effect Category[2]	Non-Equivalent Comparison Group	No Comparison Group
Lovett et al. (2008)	Students randomly assigned to an eight-week accelerated OLI-Statistics hybrid course (in which students met with the instructor to review and reinforce material) performed better on the final exam than students randomly assigned to the traditional 15-week statistics course.	N/A	Small positive		
McClendon & McArdle (2002)	Retention was higher in courses that used the lecture mode of instruction versus the computer software, ALEKS and Academic Systems.	N/A	Trivial to moderate negative	X	
Taylor (2008)	The control group made larger gains from pre- to posttest than the ALEKS group on the algebra test, but self-reported math anxiety decreased more for the ALEKS group than for the control group, and self-reported attitudes about math improved for the ALEKS group and worsened for the control group.	-0.21 to -0.12	Small negative	X	
Zavarella & Ignash (2009)	Twenty percent of students in the lecture-based course and 42 percent of students in the blended-online course withdrew from the course by the end of the semester.	N/A	Small negative	X	
Zhu & Polianskaia (2007)	Over most years in a ten-year period, a higher percentage of students in lecture courses had higher pass rates, course completion rates, and final exam scores than students in computer-mediated courses.	N/A	Trivial to small negative	X	

Table Notes

1. Effect Size: Effect sizes are used to compare results across studies with different outcome measures and are also important in measuring meaningful changes in outcomes that may not necessarily be statistically significant. The table reports Cohen's *d* effect sizes, which can be interpreted as the standardized difference between the treatment and control group means. The author calculated Cohen's *d* based on the formulas from Thalheimer and Cook (2002). Typically, Cohen's *d* was calculated using means and standard deviations for the treatment and control groups as provided in the article, using the following formula, where *x* is the mean, *n* is the sample size, *s* is the standard deviation, and the subscripts *t* and *c* denote treatment and control. If the article did not have a comparison group but provided pre- and posttest means and standard deviations, the same formula was used:

$$d = \frac{\bar{x}_t - \bar{x}_c}{\sqrt{\frac{(n_t - 1)s_t^2 + (n_c - 1)s_c^2}{n_t + n_c}}}$$

If the means and/or standard deviations were not provided but the *F*-statistic was, Cohen's *d* was calculated using *F* and the sample sizes of the treatment and control groups:

$$d = \sqrt{F\left(\frac{n_t + n_c}{n_t n_c}\right)\left(\frac{n_t + n_c}{n_t + n_c - 2}\right)}$$

If the means and/or standard deviations were not provided but the *t*-statistic was, Cohen's *d* was calculated using *t* and the sample sizes of the treatment and control groups:

$$d = t\sqrt{\left(\frac{n_t + n_c}{n_t\, n_c}\right)\left(\frac{n_t + n_c}{n_t + n_c - 2}\right)}$$

For articles that do not report the necessary information to calculate Cohen's *d*, "N/A" is written in the effect size column.

2. Effect Category: Hopkins (2009) proposes a scale that can be used to compare traditional effect size estimates to differences in percentages, which most articles do report, allowing for an estimation of their effect size category. The following scale was used to compare effect size estimates and percentage differences, in order to categorize them by size:

Size:	**Trivial**	**Small**	**Moderate**	**Large**	**Very Large**	**Nearly Perfect**
Standardized difference in means (*d*)	0–0.2	0.2–0.6	0.6–1.2	1.2–2.0	2.0–4.0	4.0–∞
Percentage difference	0–10	10–30	30–50	50–70	70–90	90–100