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EDUCATION TECHNOLOGY:
AN EVIDENCE-BASED REVIEW

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ABSTRACT

In recent years, there has been widespread excitement around the potential for technology to transform learning. As investments in education technology continue to grow, students, parents, and teachers face a seemingly endless array of education technologies from which to choose—from digital personalized learning platforms to educational games to online courses. Amidst the excitement, it is important to step back and understand how technology can help—or in some cases hinder—how students learn. This review paper synthesizes and discusses experimental evidence on the effectiveness of technology-based approaches in education and outlines areas for future inquiry. In particular, we examine RCTs across the following categories of education technology: (1) access to technology, (2) computer-assisted learning, (3) technology-enabled behavioral interventions in education, and (4) online learning. While this review focuses on literature from developed countries, it also draws upon extensive research from developing countries. We hope this literature review will advance the knowledge base of how technology can be used to support education, outline key areas for new experimental research, and help drive improvements to the policies, programs, and structures that contribute to successful teaching and learning.

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1. Introduction

Technological innovation over the past two decades has indelibly altered today's education landscape. Revolutionary advances in information and communications technology (ICT)—particularly disciplines associated with computers, mobile phones, and the Internet—have precipitated a renaissance in education technology (ed-tech), a term we use here to refer to any ICT application that aims to improve education. In the United States, the market for PreK-12 software alone had exceeded $8 billion[1], and a recent industry report projects an estimated value of $252 billion for the global ed-tech industry by 2020.[2] Governments, schools, and families increasingly value technology as a central part of the education process, and invest accordingly.[3] In the coming years, emerging fields like machine learning, big data, and artificial intelligence will likely compound the influence of these technologies even further, expanding the already dizzying range of available education products, and speeding up cycles of learning and adjustment.

Collectively, these technologies offer the potential to open doors and build bridges by expanding access to quality education, facilitating communication between educators, students, and families, and alleviating frictions across a wide variety of educational contexts from early childhood through adulthood. For example, educational software developers work to enable educators to deliver the latest learning science advances to schools in inner cities and remote rural areas alike. The proliferation of cell phones and growing ease in connecting them to

[1] SIIA, 2015. http://www.siia.net/Press/SIIA-Estimates-838-Billion-Dollars-US-Market-for-PreK-12-Educational-Software-and-Digital-Content.
[2] Morrison, 2017. https://www.forbes.com/sites/nickmorrison/2017/05/09/google-leapfrogs-rivals-to-be-classroom-king/#32966ae927a6.
[3] Bulman and Fairlie, 2016.

Internet-based information systems has enabled the scaling of automated text messaging systems that aim to inform, simplify, and encourage students and their parents as they traverse difficult sticking points in education, like the transition to college. And online educational institutions may bring opportunities to earn degrees to students who would otherwise be constrained by work, families, disabilities, or other barriers to traditional higher education.

But the rapid proliferation of new technologies within education has proved to be a double-edged sword. The speed at which new technologies and intervention models are reaching the market has far outpaced the ability of policy researchers to keep up with evaluating them. The situation is well-summarized by a recent headline: "Ed-Tech Surges Internationally—and Choices for Schools Become More Confusing."[4] While most agree that ed-tech can be helpful under some circumstances, researchers and educators are far from a consensus on what types of ed-tech are most worth investing in and in which contexts.

Furthermore, the transformations associated with ed-tech are occurring in a context of deep and persistent inequality. Despite expanding access to some technologies, the digital divide remains very real and very big. While 98 percent of children in United States households with incomes exceeding $100,000 per year have a computer at home, only 67 percent of children in households with incomes lower than $25,000 have them.[5] Even when disadvantaged students can physically access technology, they may lack the guidance needed for productive utilization—a "digital-use divide."[6] Depending on design and implementation, education technologies could alleviate or aggravate existing inequalities. Equity considerations thus add another layer to the need for caution when implementing technology-based education programs.

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[4] Molnar, 2017. https://marketbrief.edweek.org/marketplace-k-12/ed-tech-surges-internationally-choices-schools-become-confusing/.

[5] Bulman and Fairlie, 2016.

[6] Brotman, 2016. https://www.brookings.edu/blog/techtank/2016/01/28/the-real-digital-divide-in-educational-technology/.

Of course, not every intervention model can be evaluated, and the extent of success inevitably varies across educational approaches and contexts even within well-established fields. But the speed and scale with which many ed-tech interventions are being adopted, along with the enormous impact they could have over the next generation, demand a closer look at what we know. To confront this issue, the present review takes stock of rigorous quantitative studies on technology-based education interventions that have been conducted so far, with the goal of identifying policy-relevant insights and highlighting key areas for future inquiry. In particular, for reasons explained in the following section, we assembled what we believe to be a comprehensive list of all publicly available studies on technology-based education interventions that report findings from studies following either of two research designs, randomized control trials or regression discontinuity designs, and based our analyses primarily on these studies.

In the next section, we discuss our literature review methodology in greater depth. Sections 3-6 constitute the core of the review—these sections respectively synthesize the evidence on the four topic areas that encapsulate the overwhelming majority of studies that we included: 1) access to technology, 2) computer-assisted learning, 3) online courses, and 4) behavioral interventions. Section 7 offers concluding observations and considers several of the priority areas for future research that we consider vital to ongoing efforts at more effectively and equitably leveraging technology for learning.

2. Literature Review Methodology

Several recent reviews have synthesized empirical evidence relevant to aspects of ed-tech policy.[7] The present paper aims to contribute to these efforts in two main ways. First, while existing reviews have covered subsets of ed-tech, no recent review has attempted to cover the full range of ed-tech interventions. In particular, no previous review to our knowledge brings together computer- and internet-based learning on one hand and technology-based behavioral interventions on the other. Of course, expanding our scope must come with some sacrifice—it would not be feasible to meaningfully integrate all studies relating to all areas of ed-tech into a single paper. Instead, we focus on studies presenting evidence from randomized control trials (RCT) and regression discontinuity designs (RDDs). Our core focus on RCT- and RDD-based studies constitutes a second unique contribution of this review—we argue that, in addition to helping us define sufficiently clear and narrow inclusion conditions, a focus on RCTs and RDDs adds a productive voice to broader and more methodologically-diverse policy research dialogues in an environment characterized by complex tangles of cause and effect.

Why focus on RCTs and RDDs? In the fields of program evaluation and applied microeconomics, RCTs—when properly implemented—are generally considered the strongest research design framework for quantitatively estimating average causal effects.[8] RCTs are randomized experiments, studies in which the researcher randomly allocates some participants into one or more treatment group(s) subjected to an intervention, program, or policy of interest, and other participants into a control group representing the counterfactual—what would have

[7] Bulman and Fairlie, 2016; Lavecchia, Liu, and Philip Oreopoulos, 2014; Means et al., 2010.
[8] Angrist and Pischke, 2008.

happened without the program.[9] Randomization assures that neither observable nor unobservable characteristics of participants predict assignment, "and hence that any difference between treatment and control…reflects the impact of the treatment."[10] In other words, when done correctly, randomization ensures that we are comparing apples to apples and allows us to be confident that the impacts we observe are due to the treatment rather than some other factor. Yet as a result of cost, ethics, and a variety of other barriers, RCTs are not always possible to conduct.

Over the past several decades, methodologists have developed a toolkit of research designs, known broadly as *quasi-experiments*, that aim to approximate experimental research to the greatest extent possible using observational data. Commonly used examples include instrumental variable, difference-in-difference, and propensity-score matching designs. Regression discontinuity designs (RDDs) are quasi-experiments that identify a well-defined cutoff threshold which defines a change in eligibility or program status for those above it—for instance, the minimum test score required for a student to be eligible for financial aid. While very high-scoring and very low-scoring students likely differ from one another in ways other than their eligibility for financial aid, "it may be plausible to think that treatment status is 'as good as randomly assigned' among the subsample of observations that fall just above and just below the threshold."[11] So, when some basic assumptions are met, the jump in an outcome between those just above and those just below the threshold can be interpreted as the causal effect of the intervention in question for those near the threshold.[12]

[9] Duflo, Glennerster, and Kremer 2008; Glennerster and Takavarasha, 2013.
[10] Banerjee and Duflo, 2017.
[11] Lee and Card, 2008.
[12] Imbens and Lemieux, 2008; Thistlewaite and Campbell, 1960.

RDDs can only be used in situations with a well-defined threshold that determines whether a study participant receives the intervention. We chose to include them but not other quasi-experimental designs because they can be as convincing as RCTs in their identification of average causal effects. With minimal sensitivity to underlying theoretical assumptions, RDDs with large samples and a well-defined cut-off produce estimated program effects identical to conducting RCTs for participants at the cut-off.[13] Although RDDs are quasi-experiments, in the remainder of this review we refer to the RCTs and RDDs included in this review as *experimental research* for simplicity. We chose to focus on RCTs and RDDs not because we believe they are inherently more valuable than studies following other research designs, but because we felt that the policy literature on ed-tech is flooded with observational research and could benefit from a synthesis of evidence from the designs most likely to produce unbiased estimates of causal effects. Furthermore, we introduce, frame, and interpret the experimental results in the context of broader observational literatures.

RCTs and RDDs estimate the impact of a program or policy on outcomes of interest. But the estimates they come up with are sometimes difficult to compare with one another given that studies test for impact on different outcomes using different measurement tools, in populations that differ in their internal diversity. While these differences can never be completely eliminated and effect sizes must always be considered in the contexts within which they were identified, standard deviations offer a roughly comparable unit that can give us a broad sense of the general magnitude of impact across program contexts. Standard deviations essentially represent the effect size relative to variation in the outcome measurement. Economists studying education generally follow the rule of thumb that less than 10 percent of a standard deviation is small, 10

[13] Berk et al., 2010; Cook and Wong, 2008; Shadish et al., 2011.

percent to 25 percent is encouraging, 25 to 40 percent is large, and above 40 percent is very large. We report effect sizes in standard deviations whenever the relevant data is available below to facilitate comparison, while cautioning that these effect sizes must be considered in context to be meaningful.

We also limited our core focus to studies conducted within developed countries, although we touch on research conducted in developing countries where relevant to the discussion. After considering both literatures, we determined that the circumstances surrounding the ed-tech interventions that have so far been experimentally studied differed too greatly across developed and developing country education systems to allow for integrating findings from both in a way that would yield meaningful policy implications. Our decision to focus on the developed rather than developing world in particular was driven by this review's goal of analyzing experimental research on the full range of ed-tech interventions. While experimental policy and evaluation literature on certain classes of ed-tech literature like computer distribution and computer-assisted learning have already begun to flourish in the developing world, experimental research on other areas like technology-based behavioral interventions is less developed there so far.

Our first task in constructing this review was thus to collect all publicly available studies using RCT or RDD designs within developed countries that estimate the effects of an ed-tech intervention on any education-related outcome. To locate the studies, we assembled a list of search terms, and used these to search a range of academic search engines, leading economics and education journals, and evaluation databases. To ensure that no relevant studies had been omitted, we followed backward and forward citations for all included articles and conducted consultations with leading researchers, evaluators, and practitioners in the field. Given that much of the relevant research is recent and has been conducted from both within and outside of

academia—as well as to avoid publication bias—we chose not to exclude any studies based on their publication status. Our final list of included studies consists of published academic articles, working papers, evaluation reports, and unpublished manuscripts. See our references section for a complete list of studies we reviewed.

Once the articles had been assembled, we divided them into the four categories into which we felt that they most naturally clustered: access to technology, computer-assisted learning, technology-based behavioral interventions in education, and online courses. Although not all studies fit neatly into these categories and there is some overlap, we felt that these four best encapsulated the differences in the studies' underlying themes, motivations, and theories of change. The full list of studies is contained—separated by category—in **Tables 1-4.**

Within each category, we closely read all studies and organized them further according to the approach of the intervention evaluated. We then considered each study's findings in light of the others', taking into account to the greatest extent possible variations in both the nature of the programs evaluated, the contexts in which they are implemented, and the specific research designs with which they study. Where relevant, we also contrasted findings from these studies with findings from observational research and from developing countries. In the remainder of the review, we present the results of this analysis.

3. Access to Technology

3.1 Background and Context

A natural starting point when exploring the effects of ed-tech is to consider what happens when students are provided with increased access to computers or the Internet. Since the

acceleration in technology's incorporation into the classroom first took off during the 1990s, governments and other stakeholders have invested substantial resources in an array of computer and internet distribution and subsidy initiatives. We identified 11 RCT and 4 RDD papers[14] on such initiatives, presented in **Table 1**. Overall, the interventions were effective at increasing use of computers and improving computer skills. These outcomes are noteworthy given the logistical challenges of technology distribution—particularly within lower-capacity and otherwise disadvantaged delivery contexts—and the potential reluctance of students and educators to change their routines by incorporating the technologies. Results were more mixed for academic achievement and other learning outcomes, but the research suggests areas of promise here as well, particularly computer distribution at the postsecondary level and distribution at the K-12 level when combined with additional learning software. In the remainder of this section, we provide a brief overview of the policy context of technology access initiatives before taking a closer look at the empirical findings and discussing implications for future research priorities.

A large and growing share of students in developed countries can now access computers with high-speed internet at home and at school. Today, nearly three-quarters of American adults have broadband access at home—a remarkable increase from only 1 percent of adults in 2000.[15] Among adults with children, the rate of at-home broadband access is even higher. A 2015 Pew Research Center study found that 82.5 percent of American households with school-age children have broadband access.[16]

[14] The study of the effects of Internet speed in England by Faber et al. is an exception in that it does not directly evaluate a technology access initiative, but instead leverages a coincidental divergence in internet speeds for an RDD examination of effects on education. But the study nonetheless shares the rationale of the rest in attempting to identify the educational effects of improved Internet access.

[15] Pew Research Center, 2017. http://www.pewinternet.org/fact-sheet/internet-broadband/.

[16] Horrigan, 2015. http://www.pewresearch.org/fact-tank/2015/04/20/the-numbers-behind-the-broadband-homework-gap/.

But damaging holes in coverage remain. Approximately 5 million school-age children do not have a broadband internet connection at home,[17] potentially leading to a "homework gap"[18] and other compounding layers of disadvantage. Students without computers or Internet are likely to be the students who could most benefit from a boost in human capital, as they are much more likely to come from lower-income households: "In the United States, 98 percent of the 12 million schoolchildren living in households with $100,000 or more in income have access to a computer at home, but only 67 percent of the 12 million schoolchildren living in households with less than $25,000 in income have access."[19] And underrepresented minority students disproportionately lack access: only 78 percent of African-American and Hispanic schoolchildren have computers at home, in contrast to 92 percent of white schoolchildren.[20] There is also a stark technology access divide between rural and urban areas.[21]

Several program models have emerged to address these gaps in access to technology. One model that has recently risen to prominence has been "one-to-one" technology, "in which all the students in a class, grade level, school, or district are provided computers for use throughout the school day and, in some cases, at home".[22] Several one-to-one initiatives have been implemented at large scales. For instance, the state of Maine provides all of its middle and high school students with laptops for use during the school year.[23] More recently, some school districts around the country have been pairing students up with tablets.[24] One-to-one distribution has also

[17] Anderson, 2017. http://www.pewresearch.org/fact-tank/2017/03/22/digital-divide-persists-even-as-lower-income-americans-make-gains-in-tech-adoption/.
[18] Kang, 2016. https://www.nytimes.com/2016/02/23/technology/fcc-internet-access-school.html.
[19] Bulman and Fairlie, 2016.
[20] Ibid, 263.
[21] West and Karsten, 2016. https://www.brookings.edu/blog/techtank/2016/07/18/rural-and-urban-america-divided-by-broadband-access/.
[22] Zheng et al., 2016.
[23] Maine Learning Technology Initiative (MLTI), http://maine.gov/doe/mlti/about/history/index.html
[24] McLester, 2012. https://www.districtadministration.com/article/one-tablet-child-0.

caught on within developing countries, and governments as diverse as those of Peru, Kenya, Turkey, and India have invested in variations of such programs.[25] One particularly prominent civic-led one-to-one initiative has been the One Laptop Per Child (OLPC) program, which aims to "empower the children of developing countries to learn by providing one connected laptop to every school-age child."[26] OLPC has distributed laptops to disadvantaged students in roughly a dozen developing countries, along with two US cities. [27]

Other initiatives have provided schools with subsidies to buy computers or software, or to acquire or improve internet connections**.** In 1997, the United States federal government launched its largest ever ed-tech program to connect U.S. schools and classrooms to the internet. Known as E-Rate, the program has connected 97 percent of U.S. classrooms to the internet. In 2013, President Barack Obama announced a new initiative known as ConnectED, which sought to bring high-speed broadband to 99 percent of K-12 students by 2018.[28] The initiative helped provide an additional 20 million students[29] with in-classroom access to broadband. Both the private and public sectors have invested heavily to increase broadband access around the country. Since 2009, more than 115,000 miles of network infrastructure have been built at a cost of more than $260 billion.[30]

[25] Trucano, 2013. http://blogs.worldbank.org/edutech/big-educational-laptop-and-tablet-projects-ten-countries; BBC, 2013. http://www.bbc.com/news/world-asia-india-21738237; Simhan, 2011. http://www.thehindubusinessline.com/economy/policy/distribution-of-free-laptops-to-tn-students-from-sept-15/article2123738.ece.

[26] One Laptop per Child, http://laptop.org/en/vision/mission/.

[27] Ibid. http://one.laptop.org/stories.

[28] Benton Foundation, 2013. https://www.benton.org/initiatives/e-rate?page=2%2C1%2C1.

[29] Obama White House Archives, https://obamawhitehouse.archives.gov/issues/education/k-12/connected.

[30] Council of Economic Advisers, 2016. https://obamawhitehouse.archives.gov/sites/default/files/page/files/20160308_broadband_cea_issue_brief.pdf.

3.2 Investing in Access

Given the wave of investments and policy interest in access to technology, what have been the effects of access programs? With only a handful of RCT and RDD papers on the subject, the experimental literature on its own cannot say much definitively. However, these studies provide valuable suggestive insights, particularly when viewed within the context of the broader quasi-experimental and observational literatures. In particular, seven articles report on RCTs that were conducted by Robert Fairlie and collaborators: two[31] on an RCT conducted in 15 California middle and high schools, and five[32] on an RCT conducted in a community college[33] in California. Four papers are RDD studies on the educational effects of programs subsidizing household computers for students in Romania,[34] school computers in the Netherlands,[35] and internet access in California,[36] plus a study of coincidental internet speed variation in England.[37] Information on these studies is presented in **Table 1**.

Despite the differences in interventions and settings explored within the studies, the papers consistently report success in programs' intended proximate outcomes—distributing computers, increasing time spent using computers, or decreasing time spent accessing computers (e.g., less time waiting for computers in labs to become available). For example, among students in California who were randomly assigned to receive free laptops, computer ownership reportedly increased by 55 percentage points, computer usage reportedly increased by 2.5 more hours per week, and the likelihood of at-home internet connection increased by 25 percentage

[31] Fairlie and Kalil, 2017; Fairlie and Robinson, 2013.
[32] Fairlie, 2012A; Fairlie, 2012B; Fairlie and Bahr, 2017; Fairlie and Grunberg, 2014; Fairlie and London, 2012.
[33] The term "community college" in the US context generally refers to postsecondary institutions that provide only two-year degrees, traditionally catering in particular to disadvantaged or nontraditional students.
[34] Malamud and Pop-Eleches, 2011.
[35] Leuven et al., 2007.
[36] Goolsbee and Guryan, 2006.
[37] Faber et al., 2015.

points relative to those who were not assigned to receive free laptops.[38] Though they may seem intuitive, these findings are noteworthy considering that the significant resources required to expand computer and Internet access may be wasted because of the logistical difficulties of distribution. And students and teachers facing constraints on time and cognitive capacity may be reluctant to adopt technologies in the ways intended by providers.

Findings of effects on learning outcomes have been more mixed, although they do suggest some promising possibilities—in particular for students at the post-secondary level. As reported in four recent papers,[39] an intervention that distributed laptops to low-income students at a community college in Northern California saw a range of modest but positive effects, with an overall impact on an academic performance index of 0.137 standard deviations[40]. The academic performance index is a measure the authors constructed to aggregate four separate outcomes: course success rate, the likelihood of taking a course for a grade, the likelihood of taking a transfer course for a four-year college, and graduation rate. Further analysis suggested that the benefits occurred not by increasing the time that students spend using computers, but by saving them time costs involved with using computers in the college's computer labs. Two separate papers reporting on the same study also find that positive academic effects are significantly stronger for minority than for non-minority students[41], and that the program increased computer skills most strongly for minorities, women, lower-income, and younger students.[42] However, a follow-up study showed no impact on earnings seven years after the program was implemented.[43]

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[38] Fairlie and Robinson, 2013.
[39] Fairlie, 2012A; Fairlie, 2012B; Fairlie and Grunberg, 2014; Fairlie and London, 2012.
[40] Fairlie and London, 2011.
[41] Fairlie, 2012A.
[42] Fairlie, 2012B.
[43] Fairlie and Bahr, 20167.

The few primary- and secondary-level computer distribution programs that have been experimentally evaluated have yielded less evidence of positive impact. In the only such study we are aware of that met our inclusion criteria, 6th to 10th grade students in 15 middle and high schools across five California districts were randomly selected to receive free computers. Overall findings suggest that "increasing access to home computers among students who do not already have access is unlikely to greatly improve educational outcomes, but is also unlikely to negatively affect outcomes." In particular, no significant impact—positive or negative—was found on homework time, grades, standardized test scores, attendance, or several other outcomes.[44] One intervention that subsidized computers for households in Romania and another that subsidized schools in purchasing computers and software in the Netherlands both found negative impacts on achievement outcomes, with the Romania study suggesting that this could be in part a result of the students spending more time playing games.[45] However, the negative effects in the Netherlands study are weak and generally low, and in the Romania study negative impacts on academic achievement are accompanied by positive impacts on computer skills and cognitive test scores. And studies that respectively looked at internet subsidies in the US[46] and connection speed in England[47] similarly found no evidence of substantial positive or negative impact on academic achievement.

Where do these findings stand within the broader literature on interventions related to technology access? Experimental research conducted in the developing world have, for the most part, come up with similar results. Interventions giving computers to schools in Colombia,[48] One

[44] Fairlie and Robinson, 2013.
[45] Leuven et al., 2007; Malamud and Pop-Eleches, 2011.
[46] Goolsbee and Guryan, 2006.
[47] Faber et al., 2015.
[48] Barrera-Osorio and Linden, 2009; Rodriguez et al., 2015 find a positive impact from the same program after more time had elapsed, but the latter study is primarily non-experimental.

Laptop Per Child efforts in Peru,[49] and tablets distributed to students in Kenya[50] showed no impact on learning outcomes in the experimental studies, while one of the interventions in Peru yielded positive effects on cognitive outcomes and an intervention in China[51] significantly improved math scores. Perhaps instructively, the intervention in China was the only one of the computer distribution initiatives in which computers were reliably equipped with educational software that was actually used by the students.

Observational and quasi-experimental studies in both developed and developing countries have, on the other hand, tended to find more positive results. One recent review of observational and experimental studies on one-to-one programs implemented between 2001 and 2015 finds that an expansive range of positive impacts have been documented, including "…increased academic achievement in science, writing, math, and English; increased technology use for varied learning purposes; more student-centered, individualized, and project-based instruction; enhanced engagement and enthusiasm among students; and improved teacher-student and home–-school relationships,"[52] although many of the studies reviewed are not equipped for rigorous causal inference.

3.3 Looking Forward

What insights does the experimental literature bring to current policy debates and considerations for future research? First, more research is needed on efforts to improve access to technology at the post-secondary level. As helpful as computers and the Internet may be for

[49] Beuermann et al., 2015; Cristia et al., 2012.
[50] Piper et al., 2016.
[51] Mo et al., 2015.
[52] Zheng et al., 2016.

primary and secondary students, college demands a variety of more complex tasks that, in many cases, truly necessitate the need for a computer. Although students enrolled in colleges are more likely to have computer access,[53] computer ownership and Internet access are far from universal among lower-income and otherwise disadvantaged students, and accessing computers at labs may waste scarce time. Notwithstanding the lack of impact found on earnings, Fairlie's research has shown promising results in this area, but a single study at a single college is far from sufficient for making policy claims.

Second, while the few technology access programs that have been experimentally evaluated at the primary and secondary levels show few positive effects on academic achievement, improving access in combination with other activities may yield better results. For instance, the survey conducted for the Romania study discussed above found some suggestive evidence that the negative effects of home computers on grades was attenuated with certain parental rules—approaches to regulating children's computer use or providing more structure and guidance for how the computer should be used may be worth studying. And, although increasing access to computers and Internet may not on their own measurably improve academic achievement, they have been successful in increasing the time and/or ease of use. This observation, in combination with the positive results found for educational software discussed in the following section, suggests that the most promising policy models may be those that integrate hardware distribution with more specific learning programs. We turn to discussing such programs in the following section.

[53] Anderson, 2015. http://www.pewinternet.org/2015/10/29/the-demographics-of-device-ownership/; School Guides, 2014. http://www.schoolguides.com/College_News/Survey_reveals_how_much_college_students_rely_on_technology_643742.html ; MarketWatch, 2014. http://www.marketwatch.com/story/laptops-move-to-the-head-of-the-class-among-college-students-according-to-amd-back-to-school-survey-2014-07-10.

Table 1

Author	Intervention	Data Source	Sample	Findings	Education Setting
Carter, Greenberg, Walker (2016)	Prohibiting use of computers during a college economics class	West Point student outcomes data	50 classrooms and 726 students in West Point, New York	Average final exam scores among students assigned to classrooms that allowed computers were 0.18 SDs lower than exam scores of students in classrooms that prohibited computers.	Post-secondary
Faber, Sanchis-Guarner, and Weinhardt (2015)	Differences in broadband connection speeds	Administrative test score records, telecommunication network data, survey microdata on student time use and internet use in England	580,000 residential postcodes in England	Null results, "precisely estimated zero effect"	Primary & secondary
Fairlie (2012A)	One-to-one laptop distribution	Administrative data from the original application to the college and baseline survey of treatment and control	286 students community college students receiving financial aid in California	(1) 0.15 GPA difference (2) 6.5 percentage point difference in course completion rates (3) 8.6 percentage point difference for course success rate (4) No impact on graduation rate	Post-secondary
Fairlie (2012B)	One-to-one laptop distribution	Administrative data from original application to college and administrative data from Butte College	286 students community college students receiving financial aid in California	(1) ITT increase in high-level computer skills of 17 percentage points (2) Benefits appear to be the strongest among young, minority, low-income, and female students	Post-secondary
Fairlie (2014)	One-to-one laptop distribution	Data from Current Popular Survey Computer and Internet Use Supplements by the U.S. Bureau of Labor Statistics and Census Bureau and survey data on time use	1123 children enrolled in grades 6-10 in 15 different middle and high schools in 5 school districts in California	No evidence is found indicating that personal computers crowd out homework time and effort for disadvantaged boys relative to girls. Home computers also do not have negative effects on educational outcomes such as grades, test scores, courses completed, and	Middle & High School

				tardies for disadvantaged boys relative to girls.	
Fairlie and Bahr (2017)	One-to-one laptop distribution	Administrative earnings data collected by the California State Employment Development Department UI system, administrative database of the California Community College (CCC) system and National Student Clearinghouse (NSC)	286 students community college students receiving financial aid in California	The experiment does not provide any evidence that computer skills have short- or-medium run effects on earnings.	Post-secondary
Fairlie and Grunberg (2014)	One-to-one laptop distribution	Administrative data from the original application to the college, including career goals, baseline survey, and administrative data on all courses taken by study participants	286 students community college students receiving financial aid in California	4.5 percentage point increase in transferable courses enrollment than the control group of students not receiving free computers	Post-secondary
Fairlie and Kalil (2017)	Free home computers for students in grades 6-10	Baseline survey, administrative data on school participation for all children covering the entire academic year, and follow-up survey	1123 children enrolled in grades 6-10 in 15 different middle and high schools in 5 school districts in California.	(1) No negative effects on social development found (2) increase in online social networking, but also more in-person friend interaction	Middle & High School
Fairlie and Kalil[54] (2016)	Free home computers for students in grades 6-10	School-provided administrative data, baseline and follow up survey	1123 children enrolled in grades 6-10 in 15 different middle and high schools in 5 school districts in California.	No find evidence that home computers increase cyberbullying.	Middle & High School

[54] This is related working paper to Fairlie and Kalil, 2017.

Fairlie and London (2012)	One-to-one laptop distribution	Administrative data provided by the college, baseline survey, and follow up survey	286 students community college students receiving financial aid in California	(1) 0.14 SDs improvement "summary index of educational outcomes" that includes variables like grades and degree completion (2) benefits strongest for students who live farther from campus or have a job	Post-secondary
Fairlie and Robinson (2013)	One-to-one laptop distribution	Administrative data from schools, follow up survey, standardized test scores, pretreatment administrative data and baseline survey	6-10th graders in 15 middle and high schools in 5 districts in California; vast majority of sample is middle school students	Null results	Middle & High School
Goolsbee and Guryan (2006)	E-Rate, subsidy for internet in schools	Administrative data on E-rate funding applications. Stanford Achievement Test data	Every California public school	Null results on academic outcomes. By the final year of the sample, there were approximately 68 percent more Internet-connected classrooms per teacher.	Primary, Middle & High School
Kirabo, Jackson, and Makarin (2016)	Middle school math teachers given access to websites that warehouse "off the self" instructional materials	Administrative records for teachers and their students, student results on the math portion of the Virginia Standards of Learning (SoL) assessment, teacher survey data, and student surveys	Across all grade levels, 59,186 Virginia students were enrolled in 62 Chesterfield public schools; In total, 50,569 students were enrolled in 82 Henrico public schools; and 18,264 students were enrolled in 26 Hanover public schools	Only providing teachers with online access to the lessons increased students' math achievement by 0.06 of a SD, but providing teachers with online access to the lessons along with supports to promote their use increased students' math achievement by 0.09 of a SD.	Middle School
Leuven et al. (2007)	Subsidies for computers and software in under-resourced schools	Administrative data on the numbers of pupils of different social backgrounds, pupils' results in nationwide tests, and school-level data of the share of female teachers and teachers' average age	267 schools in the Netherlands that had at least 70 percent of pupils belonging to the disadvantaged minority group in 1998 and 551 schools that had at least 70 percent of pupils belonging to the	(1) Null and mildly negative results (2) Seems especially detrimental for girls' achievement	Primary

			disadvantaged minority group in 1999		
Malamud and Pop-Eleches (2011)	Euro 200 program, subsidy for low-income families with schoolchildren to buy computers	Household survey, child survey, un-timed cognitive test, and computer test and self-reported computer fluency	Over 3,000 households from several regions of Romania	(1) Both positive and negative effects (2) .25 -.33 SD reduction in Math/English/Romanian (3) .25 SD improvement in computer skills (4) Some evidence of improvement in cognitive skills	Primary & Secondary

4. Computer-Assisted Learning

4.1 Background and Overview

Computer and learning scientists have been working for decades to develop software to deliver educational content, and the popularity of these programs has exploded in the wake of the 1990s' ICT revolution. For the purposes of this review, we refer to initiatives relating to educational software as computer-assisted learning (CAL) programs.[55] CAL programs differ from the technology distribution programs of the previous section in that they do not involve the provision of hardware for general use, but instead center on "well-defined"[56] use of specific software packages. And they differ from the online courses discussed in the following section in that they are software packages designed to develop particular skills, e.g., improving math

[55] The programs discussed in this section are also frequently discussed under the rubric of "personalized learning". While this latter term is sometimes used as a synonym for CAL, we chose to use the term CAL in this paper since definitions of personalized learning sometimes lack a technology component and because, while personalization is often a key goal of CAL, CAL programs may vary in the extent to which they focus on it.

[56] Rouse and Krueger, 2004.

computation or improving reading comprehension, rather than platforms through which to administer courses. Hundreds of companies have entered the market to meet spiking demand from educators and policymakers for CAL, resulting in the advent of a plethora of products being used daily by millions of students worldwide. Yet, to date, decisions on whether to pursue CAL and which CAL programs to use seem to have been based more on intuition than on hard evidence. To what extent and under what circumstances are CAL programs effective? In this section, we review the experimental literature on this question.

We identified 29 experimental studies of CAL programs in developed countries, all based on RCTs. While CAL can conceivably include a wide range of program types from games to research and networking tools, the CAL programs that have been evaluated experimentally generally fall within the broad category of "intelligent tutoring systems," i.e., software systems that aim to help students practice particular skills.[57] Taken together, the findings from these studies suggest that CAL programs of the types evaluated in these studies show enormous promise in improving learning outcomes, particularly when it comes to mathematics. Of the 29 studies included, only eight[58] report no effect[59] and one[60] turned up negative effects. While these eight studies evaluated programs attempting to improve a mix of language, math and other outcomes, the majority of the studies finding positive effects (15 of 20) were focused on improving math outcomes.[61] Information on these studies is presented in **Table 2.**

[57] Kulik and Fletcher, 2015.

[58] Borman et al., 2009; Cabalo et al., 2007; Campuzano et al., 2009; Cavalluzo et al., 2012; Dynarski et al., 2007; Rouse and Krueger, 2004; Rutherford et al., 2014; Van Kalveren et al., 2017. Of these eight, one (Rockoff 2015) specifically mentions that the study was underpowered.

[59] Campuzano et al., 2009 and Dynarski et al., 2007 represent notable exceptions to the overall pattern of findings. These Department of Education studies evaluated roughly a dozen CAL programs and over two years and found a general pattern of no effects. However, multiple programs are aggregated together in some of the analyses, and the multi-program design generally makes it difficult to interpret these results in the contexts of the other studies discussed here.

[60] Pane et al., 2010.

[61] Barrow et al., 2009; Beal et al., 2013; Hegedus et al., 2015; Karam et al., 2017; Kelly et al., 2013; Morgan and Ritter, 2002; Pane et al., 2014; Ragosta, 1983; Ritter et al., 2007; Roschelle et al., 2010; Roschelle et al., 2016; Singh et al., 2011; Snipes et al.,

Of those evaluated, several interventions show especially strong promise, e.g., an evaluation of a math homework program in Maine showed an effect size of 0.18 standard deviations despite involving less than 30-40 minutes per week[62], while a more intensive software-based math curriculum intervention in Texas improved seventh and eighth grade math scores by 0.63 and 0.56 standard deviations, respectively.[63] Many of the CAL interventions compare favorably with interventions like reduced class sizes, longer school days, and intensive face-to-face tutoring. In the remainder of this section, we first discuss the way CAL programs are hypothesized to improve learning by leveraging software to enable increased personalization of learning. We then review findings from studies on CAL programs in math, considering models from light-touch homework supplements to class curriculum changes to school-wide personalized learning models, before turning to the few experimental studies on CAL reading programs. Finally, we consider findings from the studies we included within the broader research context, and highlight potentially promising directions moving forward.

4.2 Educational Software in and out of the Classroom

The most prominently discussed channel through which CAL is expected to improve learning has been its potential to "personalize" education, i.e., to provide content that is better suited to the learning needs of the student in question.[64] Designers and evaluators of CAL programs tend to focus on several particular ways in which the interventions can facilitate increased personalization in learning. Perhaps most central here has been adaptivity—the

2015; Tatar et al., 2008; Wang and Woodworth, 2011. Pane 2014 only finds positive impacts on math outcomes in the second year.

[62] Roschelle et al., 2016.

[63] Roschelle et al., 2010.

[64] West, 2011.

increasingly sophisticated ability of CAL programs to harness emerging artificial intelligence and machine learning techniques to model the cognitive processes of students and offer content accordingly. When teaching a full classroom of students at different levels, a teacher can only adapt so much—this has been a longstanding issue that education researchers have attempted to overcome for decades. A variety of interventions not relying on technology have been evaluated that enable students to spend dedicated time each day learning "at the right level," and these show a great deal of promise (e.g., Banerjee et al. 2007; 2015). Such efforts can better allow students to master more basic concepts before moving on to more advanced concepts and to practice more in areas where they are struggling and less in areas that they have picked up.

Aside from directly tailoring content toward students, CAL programs can help to personalize learning by providing students with immediate or timely feedback. And they can provide teachers with rapid and regular data that can be used to calibrate focus with individual students, among other potential mechanisms of personalization. The program theories that guide the interventions evaluated in the studies that we review typically include multiple of the above dynamics in their respective visions.

While many CAL programs attempt to improve education by facilitating the increased personalization of learning, these programs vary widely in how they do so. CAL programs can range from light-touch interventions that provide practice opportunities outside of class, to more intensive interventions that provide courses with entirely new curricula, to (in a few cases) initiatives in which schools are organized entirely around CAL or CAL-like programs.

Beginning on the light-touch end, ASSISTments represents an especially promising example. ASSISTments is a math homework platform released by the Worcester Polytechnic Institute that does not require that schools adjust their curriculum or textbooks, and is available

free of charge.[65] The program is designed to carry out "formative assessments," i.e., to use "data from students' independent work to give them helpful feedback and guidance while enabling the teacher to use the data to adjust instruction to meet students' learning needs."[66] As students work through individual problems, the computer informs them about whether their answer is correct and offers guidance if necessary. Students are expected to benefit from the customized practice, as well as from the rapid feedback of responses, and data supplied to teachers (in addition to, in some cases, supplementary professional development to train the teachers on optimizing use of ASSISTments). Two small-scale proof-of-concept studies[67] found promising effects, but these studies had samples numbering only in the dozens of students and implementation time numbering only in the days.

More recently, however, a full-scale impact evaluation of an ASSISTments intervention was conducted with a sample of 2,850 seventh-graders across 43 schools in Maine.[68] The authors found that the program improved math scores for treatment students by 0.18 standard deviations. This impact is particularly noteworthy given that treatment students used the program on average for less than ten minutes per night, three to four nights per week.[69] It is worth noting that the program depends on students' ability to access a laptop or tablet. This is part of the reason that this evaluation was conducted in Maine, given its state policy of lending laptops to students. While this hurdle may raise some external validity concerns with regard to this particular study, a variety of possibilities exist for enabling access in other states, especially given that software and licensing are free so costs are otherwise low. Also noteworthy is that impact was significantly

[65] Worcester Polytechnic Institute, 2016. https://www.assistments.org/
[66] Roschelle et al., 2016.
[67] Kelly et al., 2013; Singh et al., 2011.
[68] Roschelle et al., 2016.
[69] Ibid, 6.

stronger for students at or below median than for those above, with an effect size of 0.29 standard deviations.[70]

Second, some programs move beyond homework supplements and instead offer full curricula. A prime example—perhaps the most prominent of all of the CAL products discussed in this review—is the set of Cognitive Tutor products published by Carnegie Learning. The company recommends 40 percent computer time and 60 percent class time.[71] Unlike ASSISTments, the Cognitive Tutor programs generally provided curricula for entire mathematics courses, including lesson plans, textbooks, training for teachers, and detailed guidelines. Through the tutor, students receive individualized instruction in the form of challenging problems that reflect real-world situations, enabling students to move from concrete to abstract thinking.[72] We identified nine papers reporting on experimental studies on Cognitive Tutor programs in a variety of locations, including California, Hawaii, Maryland, and Oklahoma.[73] While earlier papers were narrow in scope, a recent experiment in eight states has sought to increase the external validity of the Cognitive Tutor literature by seeking to replicate realistic scale-up conditions in a wide variety of locations.[74] They found no effect the first year, but a 0.20 standard deviation impact in the second. Interestingly, the improvement in the second year was not associated with increased fidelity of implementation, but instead with teachers reducing (although not completely eliminating) their use of the activities called for by Cognitive Tutor guidelines for non-computer class time.[75]

[70] Ibid, 8.
[71] Cabalo et al., 2007; Pane et al., 2010.
[72] Pane et al., 2014.
[73] Cabalo et al., 2007; Campuzano et al., 2009; Dynarski et al., 2007; Karam et al., 2017; Morgan and Ritter, 2002; Pane et al., 2010; Pane et al., 2014; Ragosta, 1983; Ritter et al., 2007
[74] Pane et al., 2014
[75] Ibid.

Another medium-touch intervention that has recently risen to prominence is SimCalc. Although SimCalc has not been used or tested as extensively as Cognitive Tutor programs, those studies that have been conducted demonstrate strong potential. The mission of the SimCalc project is "to democratize access to the mathematics of change and variation" (i.e. mathematics relating to algebra and leading to calculus.)[76] Based on using methods of "representational infrastructure," the program enables students to control the motions of animated characters by building or editing mathematical functions. After editing the functions, students can press a "play" button to see the corresponding animation.[77] A study on a SimCalc intervention in Texas turned up one of the largest effect sizes of any large-sample study covered in this review, with 0.63 and 0.56 standard deviation improvements in math scores for seventh and eighth graders, respectively.[78]

We identified only four studies[79] within the developed world exclusively examining reading programs. Of these, two evaluated the Fast ForWord program, a program initially designed for students with particular learning disabilities,[80] but that has been in some cases marketed and used to cope with broader reading challenges. The program works by providing students with individualized exercises in a game-like computerized environment, where students receive on screen rewards for correct answers and attentiveness to instruction. These studies—the only ones, to our knowledge, that have evaluated Fast ForWord within a broader education setting, found mostly weak and insignificant results. While Fast ForWord seems to have had more success in addressing the impairments it was designed for, experimental evidence suggests

[76] Roschelle et al., 2010.
[77] Kaput and Rochelle, 2013.
[78] Roschelle et al., 2010.
[79] Borman et al., 2009; Deault et al., 2009; Rouse and Krueger, 2004; Wijekumar et al., 2014.
[80] Rouse and Krueger, 2004.

that further adjustments or at least more testing may be needed before scale-up can be recommended.

In contrast, two recent studies[81] that evaluated a reading comprehension program called Intelligent Tutoring for the Structure Strategy (ITSS)—that teaches students a particular technique for breaking down texts—show significant positive results. It differs from Fast ForWord in that it is geared toward middle school students and aims to improve reading comprehension rather than basic literacy. ITSS is a web-based intelligent tutor that utilizes a "structure strategy" to teaching literacy that begins a lesson by describing what the student is going to learn, models the strategy, and asks the student to practice. The tutor then provides feedback to the student based on his/ her answers, and gives the student the chance to correct the answer if needed. Effect sizes on a series of reading comprehension measures ranged from 0.2 to 0.53 standard deviations.

CAL is becoming increasingly popular within the developing world as well, and an experimental literature on these interventions is growing rapidly in China[82] and India.[83] On one hand, CAL programs may prove to be more effective in developing countries given the often tight capacity constraints faced. On the other hand, infrastructure limitations and other challenges could impede CAL implementation. Findings so far have been overwhelmingly positive. One recent study conducted in Delhi[84] finds especially large effects that seem to occur through mechanisms of personalization akin to those described above. The program, called Mindspark, administers its self-developed educational software at study centers for a small fee. After a treatment period of under five months, the authors find an effect of 0.36 standard deviations on

[81] Wijekumar et al., 2012; Wijekumar et al., 2014.
[82] Bai et al., 2016; Feng et al., 2014; Lai et al., 2012; 2015; 2016; Mo et al. 2014A; 2014B; 2015.
[83] Banerjee et al., 2007; He et al., 2007; Linden et al., 2008; Muralidharan et al., 2016; Naik et al., 2016.
[84] Muralidharan et al., 2016.

math scores and 0.22 standard deviations on Hindi language scores, the two subject areas for which the program was tested. Although there is no treatment arm that offers the same content without the adaptivity component, they present strong suggestive evidence that adaptivity played a key role in accounting for the impact. There is an expansive range of levels between students within each grade, and the Mindspark program records that report the questions generated show that they matched this wide range. Given that no teacher could possibly have covered such a huge spread of levels, the authors argue that the adaptation element of the program must have played a central role in enabling its positive impact and could therefore be an integral part of a solution to the unevenness of levels that challenge many schools in India and elsewhere.

4.3 Looking Forward

As the above discussion demonstrates, CAL technologies may be able to significantly improve learning outcomes, with the evidence particularly strong for math. Supplementary programs like ASSISTments demonstrate that even programs that require only minutes each day can generate significant effects on learning outcomes. And more intensive interventions like SimCalc show that heavier-touch CAL interventions can generate transformative results. Although experimental evidence on CAL for subjects other than math remains scarce, the ITSS program has shown that positive impact in other areas is possible.

Numerous important tasks remain, however, for future researchers to complete if CAL's potential is to be efficiently leveraged. One vital area is test the extent to which learning from CAL lasts in the longer term. To what extent do effects compound or diminish in subsequent years? Another important task will be to further explore whether and when CAL can work effectively for subjects other than math. Do the cognitive processes that underpin mathematical

reasoning inherently lend themselves better to software algorithms? More broadly, which areas of education could CAL add most value to? And when are light- vs. heavy-touch interventions most appropriate and cost-effective? An important crosscurrent that undercuts many of these other concerns is the issue of implementation. One way to gain greater leverage on this issue could be to test a particular CAL program in a particular population while varying elements of the implementation plan. Finally, we still know little about how CAL programs interact with teachers' efforts. Unpacking interconnections could highlight opportunities for complementarity and synergy.

Table 2

Author	Intervention	Data Source	Sample	Findings	Subject
Barrow, Markman, and Rouse (2009)	I Can Learn© aka "Interactive Computer Aided Natural Learning"	Data from customized pre-algebra and algebra tests administered in the study sites	Eight high schools and two middle schools in three large urban school districts in the Northeast, Midwest and South) with a high proportion of minority students	(1) Students randomly assigned to the computer-aided instruction scored 0.17 SD's higher on a pre-algebra and algebra test than students assigned to traditional instruction (2) The strongest effects were for larger classes (especially with more heterogeneity in student levels) and classes with more absences, possibly indicating that impact occurs through "increased individualized instruction"	Math
Beal et al. (2013)	AnimalWatch web-based math tutoring program	Student test scores on standardized tests and project-based quizzes	58 teachers' classes (35 Treatment, 23 Control) for 6th grade. Data from over 1200 students are	The AnimalWatch program had significant effects on student scores on a state achievement test and project-based quizzes (Positive	Math

			included in the analysis (795 Treatment, 496 Control).	impact of around 0.3 SDs on scores)	
Borman, Benson, and Overman (2009)	Fast ForWord computer-based language training program	Primary data from a school administered language and reading comprehension test.	Second and seventh grade students in Baltimore who were more generally at risk for poor reading and language outcomes in eight elementary and middle schools	Null results (attributed to implementation shortcomings): (1) No statistically significant effect for second graders in reading comprehension or language; (2) There were statistically significant main effects for reading comprehension for seventh graders (effect size 0.21), but not language	Reading
Cabalo et al. (2007)	Cognitive Tutor's Bridge to Algebra program	Primary data from a standardized math assessment (Northwest Evaluation Association (NWEA))	32 pre-algebra classes in 5 schools in the Mau, Hawaii school district	Null results	Math
Campuzano et al. (2009)	16 types of software products	Primary data collection of student achievement tests, including the Stanford Achievement Test, the Iowa Tests of Basic Skills (ITBS), the California Achievement Test, the New Mexico Standards Based Assessment, the ETS End-of-Course Algebra Test, and school administrative data	Thirty-three US school districts, 132 schools, 428 teachers. It focused on school districts that had low student achievement and large proportions of students in poverty.	(1) For reading, there were no statistically significant differences between the effects the products had on standardized student test scores in the first and second year (see Dynarski et a., 2007); (2) For sixth grade math, product effects on student test scores were statistically significantly lower (more negative) in the second year than in the first year. (3) For algebra I, effects on student test	Math and Reading

				scores were statistically significantly higher (.15 SDs) in the second year than in the first year.	
Cavalluzzo et al. (2012)[85]	Kentucky Virtual Schools hybrid program for Algebra 1	Administrative data from standardized assessments (American College Testing PLAN) and 10th grade math course enrollment	47 Kentucky schools (30 of which were in rural areas) with Grade 9 Algebra classes	The treatment has no statistically significant effect for either outcome.	Math
Dynarksi et al. (2007)	16 types of software products	Primary data collection of student achievement tests, including the Stanford Achievement Test, the Iowa Tests of Basic Skills (ITBS), the California Achievement Test, the New Mexico Standards Based Assessment, the ETS End-of-Course Algebra Test, and school administrative data	Thirty-three US districts, 132 schools, and 439 teachers participated in the study. It focused on school districts that had low student achievement and large proportions of students in poverty	Test scores were not significantly higher in classrooms using selected reading and mathematics software products. (First student cohort –second cohort results reported in Campuzano et al. 2009)	Math and Reading

[85] This could also be considered a blended online learning and face-to-face intervention. In Kentucky Virtual Schools, instruction time is 60 percent face-to-face instruction and 40 percent is using online resources. The findings from this paper are consistent with the outcomes we observe in other blended classroom interventions.

Deault, Savage, and Abrami (2009)	ABRACADABRA web-based literacy program	Primary data collection of scores on tests of a range of literacy and skills attention measures.	Grade 1 students from schools in Montreal, Canada for a total of 144 students from 13 different classrooms.	(1) Overall, significant effects of the intervention were evident for about half of the reading and related measures. (2) The intervention reduced pre-intervention negative correlations between attention and learning outcomes, indicating that it may help kids with attention problems	Reading
Hegedus, Dalton, and Tapper (2015)	SimCalc interactive math software	Primary data collection using instruments to measure student learning and related factors.	7 high schools in Southeast Massachusetts of varying achievement levels	Significant impact on student learning of core algebra concepts including both procedural and conceptual problems	Math
Karam et al. (2017)	Cognitive Tutor Algebra I	Primary data collection on survey data of dosage and frequency of implementation and administrative data on student grades and Algebra 1 scores	74 middle and 73 high schools in 51 school districts representing seven states in the U.S. that varied in contexts.	(1) Use of traditional student activities in classrooms was significantly negatively associated with student outcomes on Algebra 1 for middle school in years 1 and 2 (i.e use of CTAI had a positive effect on Algebra 1 outcomes). (2) Although not statistically significant, we see similar negative associations between teachers' use of traditional instructional methods and student outcomes for middle schools in both study years and in high school in year 2	Math

Kelly et al. (2013)	ASSISTments online homework support	Student learning data collected from the ASSISTments system.	63 thirteen and fourteen year olds who were currently enrolled in an eighth grade math class, in a suburban middle school in Massachusetts.	(1) Students receiving the intervention learned reliably more with an effect size of 0.56 SDs (2) Additionally, teacher use of the homework data lead to a more robust and systematic review of the homework.	Math
Mitchell and Fox (2001)	DaisyQuest and Daisy's Castle reading game	Student learning data on various literacy outcome measures	36 US kindergarten and 36 first grade students	(1) Students receiving computer administered phonological awareness instruction and teacher delivered phonological awareness instruction showed a significant increase over the instructional technology (drawing and math software) control group. (2) The teacher-delivered group outperformed the computer administered group on several literacy measures.	Reading
Morgan and Ritter (2002)	Cognitive Tutor Algebra I	Survey data on student attitudes toward mathematics and ETS Algebra I End-of-Course test	Ninth graders in 5 junior high schools in Moore Independent School District, Oklahoma	(1) Positive effects (0.29 SDs) in math outcomes on the ETS test [0.23 SDs according to Pane et al. p. 130, reporting the WWC adjusted estimates] (2) Students receiving the CTAI program were significantly more confident and more likely to rate mathematics as useful than	Math

				students in the traditional class.	
Pane et al. (2010)	Cognitive Tutor Geometry	Student achievement data in geometry	8 high schools in Baltimore Country Public School District (BCPS); after attrition, final sample size of 699	(1) The CTAI program has negative effects on math outcomes (-0.19 SDs) (2) No effect on student attitudes toward mathematics and technology.	Math
Pane et al. (2014)	Cognitive Tutor Algebra I	Primary data collection of student achievement data on an Algebra I Proficiency Exam and school administrative data on other student characteristics and learning outcomes	74 public middle schools and 73 public high schools across seven US states and 51 school districts in urban, suburban, and rural areas	(1) No effect of CTAI in the first year (2) 0.20 SD positive impact in second year for high schools, but no significant effect for middle schools.	Math
Ragosta (1982)	Cognitive Tutor	Student learning data in mathematics collected from the CAI system and on standardized tests	Four elementary schools in Los Angeles	The curriculum was effective in raising student scores on tests derived by the CAI curriculum and on standardized tests	Math
Ritter et al. (2007)	Cognitive Tutor	Administrative data on student grades, student performance on the ETS Algebra I End-of-Course assessment and survey data on student attitudes towards math	Ninth graders in 5 junior high schools in Moore Independent School District, Oklahoma	Statistically significant effects of CTAI on student grades and Algebra I scores	Math
Rockoff (2015)	School of One	Student achievement data in math and survey data on student and teacher attitudes	Eight New York City public schools	No effects on student math outcomes, but study was not powered to detect small to moderate effects	Math

Roschelle et al. (2010)	SimCalc interactive math software	Student math scores	Seventh and eighth grade classrooms in Texas public schools	Significant effects of SimCalc on student learning (0.63 and 0.50 SDs)	Math
Roschelle et al. (2016)	ASSISTments online homework support	Student data collected from the ASSISTments system and student outcomes on an end of year standardized math assessment	2,850 seventh graders in 43 schools in Maine	Positive effects of ASSISTments on student math outcomes (0.18 SDs)	Math
Rouse and Krueger (2004)	Fast ForWord computer-based language training program	Student outcomes on measures of language and reading ability	4 schools in an urban school district in the Northeast; around 40 percent African American and 50 percent Hispanic	Null results	Reading
Rutherford et al. (2014)	Spatial-Temporal (ST) Math	Student outcomes on a standardized test series in math	13,000 students, 52 elementary schools in Southern California	Null (although positive, but small effects (0.07 SDs) at p = .089)	Math
Singh et al. (2011)	ASSISTments online homework support	Student data collected from the ASSISTments system and student outcomes on a post-test math assessment	Eight classes of eighth grade students in Maine	Positive effects (although sample size is small)	Math
Snipes et al (2015)	Elevate summer math program	Student data on tests of Algebra readiness	8th grade students from eight schools in six districts in California's Silicon Valley	(1) The Elevate Math summer program, which included daily use of Khan Academy, significantly improved math achievement and algebra readiness (0.7 SDs on a test of algebra readiness) (2) Despite significant positive effects from the program, most students were still not ready for Algebra I content.	Math

Tatar et al. (2008)	SimCalc interactive math software	Student and teacher performance on an researcher created instrument based on the Texas state assessment; survey data on teacher characteristics, school context and teacher attitudes	21 seventh grade mathematics teachers in Texas	Positive effects on student and teacher mathematics knowledge	Math
Van Klaveren et al. (2017)	Adaptive CAL program compared against a static one	Student performance data on standardized test scores	Dutch secondary schools	No statistically significant improvement from the adaptive CAL program relative to non-adaptive CAL program (however, there is no non-CAL control group)	Multiple
Wang and Woodworth (2011)	DreamBox Program and Reasoning Mind (math programs)	Student performance on the NWEA math test and other math tests	Kindergarten through 5th grade students in 3 schools in an elementary charter school network in San Francisco	(1) Dreambox treatment group scored 2.3 points higher on the NWEA math test (effect size of 0.14 SDs), and 2.9 points higher on the geometry subtest (effect size of 0.16 SDs). (2) No significant impact of Reasoning Mind on the NWEA or other tests	Math
Wijekumar et al. (2012)	ITSS (Intelligent Tutoring for Structure Strategy)	Student performance on Gray Silent Reading Test (GSRT) and researcher-designed measures	60 rural and 71 suburban 4th grade classrooms	Positive effects on language; (.1 SDs) on GSRT, (.49 SDs) on main idea quality.	Language
Wijekumar et al. (2014)	ITSS (Intelligent Tutoring for Structure Strategy)	Student performance on standardized tests and researcher designed assessments measuring reading comprehension	128 fifth-grade classrooms in 45 schools within 12 school districts in rural and suburban settings in Pennsylvania	Positive effects on literacy (0.2 SDs) and signaling (0.42 SDs) tests	Language

5. Behavioral Interventions

5.1 Background and Context

Next, we shift focus to education technologies that draw on the theory and practice of behavioral economics to guide students (and, in some cases, their parents) toward behaviors that are expected to facilitate greater academic achievement. The idea behind this approach is that people are subject to systematic biases in decision-making that lead to sub-optimal outcomes,[86] like ending up in a job one does not like because of not having studied hard enough in school. The behavioral insights literature was relatively slow to come to the education sector, but has taken off over the past several years.[87] Behavioral issues are especially important to think about in the context of education, since important long-run decisions are being made during a time when the brain's ability to think of the future is not fully developed. So, while we all face challenges in making decisions involving long run uncertain benefits and immediate costs, children and youth particularly struggle.[88] On the plus side, with this knowledge of behavioral barriers getting in the way of realizing better long-run outcomes, technology may be used to develop simple and inexpensive solutions to give individuals more support for making better choices.

We identified 47 experimental papers studying behavioral ed-tech programs. These studies evaluated programs aimed at solving a wide variety of problems and drawing on a variety

[86] Thaler and Sunstein, 2008.
[87] Koch et al., 2015; Lavecchia et al., 2014; Levitt et al., 2012.
[88] Lavecchia et al., 2014.

of techniques implemented at different points across the life course, from giving parents ideas of how to practice reading skills with their kids to reminding college students to submit the FAFSA. In particular, we identified studies of interventions across four clusters: seven on encouraging parental engagement in learning activities, 10 on attempting to improve school-parent information flows, 17 on encouraging success in transitioning to and through college, and 13 on mindset interventions. Information on the studies is presented in **Table 3**. The studies show strong promise in each of these areas, with only a few of the interventions reviewed showing no impact. In the remainder of this section, we review the evidence on each of the four clusters in turn.

5. 1 Encouraging Parental Learning Engagement During Early Childhood

Research suggests that one of the most effective means of improving educational outcomes is for parents to engage in learning activities with their children.[89] But parents report spending less time on these activities than might be expected in light of the possible benefits. The problem of low engagement is particularly acute among disadvantaged households, a pattern that may reinforce broader disparities in educational outcomes.[90] Policymakers have found cost-effective responses elusive, with even expensive and resource-intensive programs turning up modest results.[91] Yet because young children spend a great deal of time at home, school-based programs cannot substantially substitute for engagement "unless they are very intensive, extensive and expensive."[92] This dilemma has inspired a growing literature that explores whether

[89] Levine et al., 2010; Price, 2010; Sénéchal and LeFevre, 2002.
[90] Guryan et al., 2008; Kalil et., 2015; Lee and Bowen, 2006.
[91] York and Loeb, 2014.
[92] Mayer et al., 2015.

and how behavioral interventions might contribute toward reducing disparities in engagement. We identified six experimental evaluations of technology-based interventions aiming to increase the quantity and quality of time spent by parents practicing skills with their preschoolers,[93] kindergarteners,[94] or 1st-4th graders.[95] All of the programs studied relied centrally on sending text message reminders to parents, and all found positive results.

Why might nudges be expected to increase parental learning engagement within disadvantaged households? After all, behavioral interventions are unlikely to substantially address resource constraints like the time scarcity faced by low-income parents. However, the behavioral economics literature suggests that cognitive constraints as well as resource limitations lead to underinvestment. Even when cognitive burdens themselves are aggravated by resource constraints, small adjustments in the decision structures that people face can help to correct these biases and move them toward more optimal behavior.[96] So, in the present context, a behavioral economics perspective would indicate potential benefits from reminders and instructions inspiring and guiding parents toward more productive engagement.

READY4K!—a preschool literacy program implemented in San Francisco—was the earliest experimentally evaluated, technology-based intervention we identified that attempted to leverage this rationale to improve parental learning engagement. The program sent parents three text messages per week with tips and encouragement to engage in literacy activities.[97] The behavioral logic that guides READY4K! suggests that "the complexity of parenting may overwhelm some parents, leading them to underinvest in their children".[98] Furthermore, literacy

[93] Hurwitz et al., 2015; Mayer et al., 2015; Meuwissen et al., 2017; York and Loeb, 2014.
[94] Doss et al., 2017.
[95] Kraft and Monti-Nussbaum, 2017.
[96] Thaler and Sunstein, 2008.
[97] York and Loeb, 2014.
[98] Ibid.

activities constitute a case of "delayed gratification," necessitate "interrupting the status quo" and are often overcome by "limited attention."[99] So the program sends suggestions of small, easy tasks that parents can do without feeling overwhelmed; provides encouragement to sustain parents' investment in longer term gratification; provide tips for integrating the activities into daily life so that the status quo barrier can be overcome; and address attention constraints by regularly reminding parents.

The study found an impact of 0.29 standard deviations of the program on a composite score for "global early literacy parenting" measuring activities like reading to a child, pointing out words that rhyme, and taking the child to a library or museum.[100] The study also found effect sizes ranging from 0.21 to 0.34 standard deviations on PALS literacy tests.[101] The fact that the program led to an increase in specific literacy tasks but not general ones suggests that the impact was likely generated by the program's provision of specific, manageable tasks, rather than reminding parents to engage in activities they might have engaged in anyway. The effect sizes detected are impressive given the exceedingly low costs of the intervention, at less than a dollar per family.[102] A great deal could be gained from follow-up research that unpacks these findings and tests similar initiatives in new contexts.

Ensuing research has attempted to work toward untangling the specific mechanisms underpinning the effectiveness of this type of intervention, as well as better understanding potentially differing effects across subgroups. The two remaining interventions of this type for preschoolers that have been experimentally evaluated took place within midwestern Head Start

[99] Ibid.
[100] Ibid.
[101] Ibid.
[102] Ibid.

and Early Head Start centers.[103] One of these interventions provided households with tablets containing numerous children's books.[104] The treatment group additionally received three nudges—daily text message reminders to read to the kids, a goal-setting tool that asked the parents to set reading goals and reported back on whether these goals were met, and social rewards, specifically congratulatory texts or cartoons when goals were reached.[105] Following the six week study period, the group receiving the behavioral interventions used the tablet a full standard deviation more than parents who did not. They read more than twice as many books to their children, with control group families reading an average 14.8 books during the six-week intervention period while treatment group families read an average of 31.4 books.[106] The second Head Start intervention sent daily text messages to parents encouraging them to engage in any of a variety of learning activities covering reading, science, and math, and found that the treatment increased the range of learning activities that parents engaged in.[107]

As children progress from preschool to Kindergarten and then first grade, they tend to spend larger shares of their time at school. To what extent might programs like the ones described above prove effective beyond preschool? Two interventions were recently experimentally evaluated that adopt a similar model, but for kindergarteners[108] and 1st-4th graders[109] instead of preschoolers. The kindergarten intervention was an extension of READY4K!, with the evaluation including the same preschool sample as the children entered kindergarten along with additional San Francisco kindergarteners.[110] In addition to replicating

[103] Mayer et al., 2015; Hurwitz et al., 2015.
[104] Mayer et al., 2015.
[105] Ibid.
[106] Ibid.
[107] Hurwitz et al. 2015.
[108] Doss et al., 2017.
[109] Kraft and Monti-Nussbaum, 2017.
[110] Doss et al., 2017.

the same intervention within a kindergarten context, a second treatment arm was added that sent parents "personalized" and "differentiated" texts. Texts to parents in this second treatment arm contained child-specific information and sent recommendations for tasks matching the child's level. Interestingly, the researchers found the original treatment that had been effective in preschool showed no significant effects in kindergarten. However, the personalized and differentiated text messages did show substantial benefits, with children whose parents received the treatment "50 percent more likely to read at a higher level."[111]

Finally, the most recent intervention falling into this category to undergo experimental evaluation extended the idea of texting parents to encourage engagement in literacy activities to the 1st-4th grade. Recognizing that elementary students spend more time engaged in school throughout the year, this intervention targeted a specific friction point within the elementary education process—"summer reading loss"—the tendency of elementary students to fall behind in their reading skills because of the gap in practice they experience during the summer. This study finds that the texting intervention improves reading comprehension scores for students in the treatment group by 0.21-0.29 standard deviations.[112]

5.*2 Improving School-Parent Information Flows*

As children get older, the role of parents shifts away from practicing skills with their kids directly and towards encouraging the kids to put more effort into school. So, behavioral interventions for middle and high schoolers tend to focus on sending parents information on their kids' performance—for example updates on grades, attendance, and behavior—to prompt the

[111] Ibid.
[112] Kraft and Monti-Nussbaum, 2017.

parents toward providing this encouragement. If parents are constrained by a gap in information on how hard their children are working or how well they are performing, and if children are not already expending maximum effort, then closing these gaps may provide parents the opportunity to apply that alchemical combination of guidance, pressure, and support that constitutes parenting. This issue may be especially important for low-performing schools, which already exhibit lower rates of communication satisfaction from parents[113] and where parents may be relatively more constrained in their ability to absorb monitoring costs.[114] We identified 10 RCT-based studies evaluating programs that sought to leverage technology to improve the flow of information from school to parents in this way.[115] These programs followed two main approaches: first, sending information to parents that was generated anyway as part of regular school activities (like grades and attendance), and, second, having teachers send personalized messages to parents. Overall, these studies have found positive results, indicating a potentially fruitful set of opportunities.

The majority of the school-parent information flow interventions that have been experimentally evaluated fall into the first of the two categories listed above. The first intervention in this category to be experimentally evaluated was a program aimed at middle and high school students at a single public school in a low-income neighborhood of Los Angeles.[116] Parents whose children were in the treatment groups were notified when their children missed attending class or missed an assignment through text messages, phone calls, and e-mail. Following the semester-long intervention, students in the treatment group had earned GPAs and

[113] Bergman, 2015.
[114] Ibid.
[115] Balu et al., 2016; Bergman, 2015; Bergman, 2016; Bergman, Edmond-Verley et al., 2016; Bergman and Chan 2017; Bergman and Rogers 2016; Kraft and Dougherty, 2013; Kraft and Rogers, 2015; Kraft and Monti-Nussbaum., 2017; Rogers and Feller, 2016.
[116] Bergman, 2015.

standardized math test scores that were about 0.20 standard deviations over the control group.[117] An evaluation of a similar intervention—*Papás al Día* ("Parents up to Date"), carried out in two low-income municipalities of Santiago, Chile—also finds positive results, including a 0.09 standard deviation improvement in math grades, a reduction in bad behavior, and positive spillover effects within classes.[118]

While these two interventions sought to channel existing information on students' performance to parents rather than generating new information, both were somewhat labor intensive, requiring substantial manual data entry. More recent interventions have tended to automate the process to the greatest extent possible to cut down on costs. One recent experimental study evaluated the effects of a more automated school-parent information program on a sample of 22 middle and high schools in a district of West Virginia.[119] This program automatically pulled information from the school's student information system and texted it directly to parents. Parents received weekly texts stating the number of classes and/or assignments that students had missed, as well as monthly texts if their child was averaging below 70 percent on any class.[120] Because of the automation, the intervention was extremely cheap, with 32,000 text messages totaling to only $63 and training coming down to $7 per student.[121] The study showed impacts that were very impressive given the low costs of the intervention: the treatment group saw a 39 percent reduction in failed courses, an 18 percent increase in class attendance, meaning that the treatment group attended 50 more classes on average[122] and a 0.10

[117] Ibid.
[118] Berlinski et al., 2016.
[119] Bergman and Chan, 2017.
[120] Ibid.
[121] Ibid.
[122] Ibid.

standard deviation improvement in GPA.[123] Interestingly, the data suggests that parents already had a good idea of their children's final grades, but the program reduced parents' underestimation of the number of assignments their kids were missing, which likely helped to better target the pressure they placed on their kids to increase effort.[124] The strongest benefits went to those with below-average GPAs, who saw a reduction in class failures of 0.9 classes, an increase in attendance of 64 classes, and a GPA increase of 0.26 points.[125]

In contrast, another fully automated intervention that focused on exclusively on attendance showed no evidence of improving attendance rates.[126] Here, parents of New York City Public School received automated text messages on each day their student did not show up for school, in addition to weekly attendance reports. Further research will be needed to explore the extent to which this lack of impact was most likely a result of the intervention's exclusive focus on attendance, its location in New York City (which may be more saturated with automated information flows than most other environments), or something more contingent and specific to the intervention in question.

Two recent studies have highlighted an important qualification to the line of research just described.[127] While technologies that improve school-parent information flows may be effective in improving education, these effects will be heavily mediated by the extent to which the technologies are actually used. For instance, one recent study showed a letter and phone call prompting students to access an online system containing attendance and grades significantly increased rates of access and ultimately resulted in a GPA increase 0.10 points.[128] Another

[123] Ibid.
[124] Ibid.
[125] Ibid.
[126] Balu et al., 2016.
[127] Bergman, 2016.
[128] Ibid.

program—this one conducted in a dozen Washington, DC middle and high schools offered text message updates of the kind mentioned above, but varied in how the program was implemented.[129] Three treatment groups—one that received a text instructing them on how to sign up online for the service, one that received a text inviting sign-up through a text message response, and one that automatically enrolled parents in the texting program but gave them the opportunity to opt out—were contrasted with a control group that did not receive any prompt to sign up for the texting service. Only 1 percent of participants in the first group and 8 percent in the second group signed up, while only 4 percent in the automatic enrollment group chose to opt out. This massive difference in adoption shaped the effectiveness of the texting program in generating academic performance outcomes: while no significant effects on performance outcomes emerged from the first two treatment groups, the automatic enrollment group saw improvements in GPA by roughly a quarter to a third of a letter grade, and reduced class failure by roughly a fifth to a quarter.[130] These lessons on the importance of encouragement and especially opt-in systems to promote technology adoption are relevant to a broad range of ed-tech applications, but are mentioned here since they were evaluated in reference to school-parent communication intervention.

The interventions discussed so far in this sub-section attempt to transfer already-existing information to parents. Another approach that has been experimentally evaluated in the context of two separate interventions has teachers communicate personalized messages to parents. The first experimentally evaluated intervention falling into this category took place during a required summer program in a Boston charter school.[131] Parents received two communications per day for

[129] Bergman and Rogers, 2017.
[130] Ibid.
[131] Kraft and Dougherty, 2013.

five consecutive school days—a phone call from an English teacher and a text message from a math teacher. The intervention improved engagement as measured by three variables: homework completion, participation, and number of instances in which teachers had to direct students' attention back to the topic at hand.[132] Qualitative evidence suggests that this effect occurred through three mechanisms: improving relationships between students and teachers, expanding parental involvement, and increasing students' motivation.[133]

The second intervention in this category took place "during a traditional summer school program offered by a large urban school district in the Northeastern United States."[134] Here, teachers themselves wrote out one-sentence messages which were then sent to parents weekly by research assistants through text message, phone, or email.[135] Two separate program variations were given: one consisting of "positive" messages about what the student was already doing well, and the other consisting of "improvement" messages about areas that the student could use work on. Averaging across the two treatment arms, inclusion in the program led to an increase in the success rate of students passing the class and obtaining the credit, up 6.5 percentage points from an 84.2 percent passing rate in the control group. Interestingly, the impact estimate is substantially higher for the improvement treatment arm, although the experiment lacks the power to detect significance in this difference.[136] The program seems to work not by increasing the amount of time parents spend talking with their kids about school, but rather by directing the content of these conversations. The program also seems to have led to the unintended consequences of lower student perceptions of their own performance, and weaker student-teacher

[132] Ibid.
[133] Ibid.
[134] Kraft and Rogers, 2015.
[135] Ibid.
[136] Ibid.

relationships as reported by teachers also.[137] Perhaps the best of both variations could be captured by sending messages that include actionable steps as in the "improvement" version, but are more positive in tone.

Overall, other than the lack of impact generated reported by the New York City attendance program, interventions that seek to improve school-parent information flows seem highly promising. Two of the studies discussed above[138] came upon unintended anecdotal evidence to this effect when the schools they worked with decided to provide comparable interventions to sections of the control group.

5.3 ***Transitioning to and Succeeding in College***

Another area of focus for technology-based nudge interventions in the education sector has been the challenge of transitioning to and making it through college. The behavioral economics literature suggests that people—and especially children, adolescents, and young adults—tend to rely heavily on routines, and the transition to college requires students to break from routine.[139] The behavioral literature has also documented the paralyzing effect of too much information and too many choices, and the transition to college is fraught with these as well.[140] Experimental evaluations have been conducted on four main types of college-related behavioral interventions: information campaigns, nudges to complete important tasks, intensive application assistance, and college advising.

[137] Ibid.
[138] Bergman 2015; Kraft and Rogers, 2015.
[139] Lavecchia et al., 2014.
[140] Ibid.

First, several interventions have sought to leverage information technology to inexpensively provide students with more college-related information. On one hand, two relatively minimalistic interventions in the U.S. generated no impact. One of these—tested in a field experiment with a sample of over a million prospective and enrolled college students in Texas—sent one e-mail and one letter containing information about higher education tax credits, but those who received these showed no more likelihood of applying to or enrolling in college than those who did not.[141] Another intervention conducted in a single public university emailed letters to students explaining their current financial aid package and associated plans, but this information too had negligible effects.[142]

On the other hand, two information interventions implemented respectively in Canada and Chile found positive effects. The first of these interventions showed videos to students in disadvantaged Toronto high schools on the benefits of higher education, and allowed the students an opportunity to try out a financial aid calculator. Students who participated in the program reported more favorable views of higher education.[143] The other program sent eighth graders in metropolitan Santiago, Chile, DVDs containing practical information on higher education financing. Participants not only showed greater knowledge of financial aid, but also were more likely to enroll in college preparatory high schools, and also exhibited attendance rates that were 8.8 percent higher.[144] This latter intervention is also unique among programs that have been experimentally evaluated in that it targets higher education at the eighth-grade level, which could allow more time for participants to plan for college.

[141] Bergman et al., 2016.
[142] Darolia, 2016.
[143] Oreopoulos and Dunn, 2013.
[144] Dinkelman and Martínez, 2014.

Another approach to supporting the transition to college has been through nudge campaigns. Although the term "nudge" as commonly used in the behavioral economics literature can be applied to many of the interventions described throughout this section, here we use the term "nudge campaigns" to refer to interventions providing sustained efforts to guide, encourage, and/or remind program participants about one or more aspects of college success. Five recent studies suggest that nudge campaigns can be effective in improving decisions and task fulfillment surrounding financial aid and college matriculation and enrollment.

Of these, three interventions attempted to encourage better-informed financial aid decisions. One program sent students at a large community college in Baltimore County eight text messages over a period of several weeks prompting them to make more "active" financial aid decisions. The intervention resulted in a 3.1 percentage point reduction among students who received the text messages in accepting unsubsidized Stafford loans, and those who still did accept the loans borrowed less. Results were strongest among students showing less financial literacy and with more debt. The study also produced some evidence that the texts led students who had attained marginal academic success to leave school earlier.[145] Another program sent text messages to college freshmen who, as high school students, had worked with a Massachusetts-based education nonprofit called uAspire. The messages encouraged students to refile the FAFSA for their sophomore year and found an increase of nearly 14 percentage points on continuous enrollment through sophomore year among students attending community colleges (those attending four year universities already had high rates of continuous enrollment).[146] Most recently, the largest experimentally evaluated FAFSA nudge-campaign to date sent three versions of a message to low-income and first-generation students filling out the Common

[145] Barr et al., 2016.
[146] Castleman and Page, 2016.

Application encouraging them to apply early for the FAFSA. One version provided specific planning structure, one gave information on the human capital returns to college, and one attempted to advocate productive identities. No effects were found for the latter two frames, but the planning message led to a 1.1 percentage point increase in college enrollment among all recipients and 1.7 percentage points for first generation college students.[147] In addition to supporting task completion related to financial aid, one nudge campaign has been experimentally shown to reduce "summer melt," the phenomenon whereby students who are admitted to and indicate a decision to attend a particular college do not actually complete the matriculation process or do not actually show up for classes.[148]

A nudge campaign may be sufficient to induce students to think through financial aid decisions and remind them to do the right paperwork on time to enroll in and get through school. However, it is perhaps less likely that nudges would be effective at getting a student to fill out an admissions or financial aid application in the first place—this is a much more daunting task. We identified evaluations of two programs that leveraged technology for more intensive application assistance and support.[149] In the first instance of these programs, families with a college-age child who were filing their taxes at H&R block were given the opportunity to quickly file their FAFSA at the same time. This was possible as a result of a software program designed to automatically feed data from the tax entry system into the FAFSA, collecting additional FAFSA questions not covered during the course of the regular tax filing in ten or so minutes following the tax filing. College enrollment of high school seniors with parents receiving the treatment increased by 8 percentage points.[150] The program LifeAfterHighSchool, on the other hand,

[147] Bird et al., 2017.
[148] Castleman and Page, 2015.
[149] Bettinger et al., 2012; Oreopoulos and Ford, 2016.
[150] Bettinger et al., 2012.

focused on providing support for the admissions process directly to students by incorporating relevant activities into the high school curriculum.[151] The program aimed to ensure that every senior in high schools given the program graduate from high school with a college program offer of acceptance and a financial aid package. The program consisted of workshops involving interactive activities, for instance having students enter their grades into a computer program, which would then generate a list of local programs in their area for which they would likely be accepted if they applied. In addition to large gains in application rates, college enrollment increased by about nine percentage points among the seniors who had not been taking any university-track courses.[152]

Finally, two recent studies have examined the extent to which technology can be leveraged to increase access to college advising. One experiment conducted at a large Canadian university tested three treatment arms: one-on-one coaching, an online exercise, and a text messaging support program. Only the one-on-one coaching arm showed significant results, potentially indicating limits in using electronic communication in helping foster longer-term academic performance.[153] The other study evaluated a program at Georgia State University that leveraged AI technology in developing a texting program with AdmitHub that sent customized messages to students guiding them through many aspects of the college enrollment process.[154] The "augmented intelligence technology" upon which the program was based made it possible for the computer to respond to a large majority of incoming questions, saving scarce time for

[151] Oreopoulos and Ford, 2016
[152] Ibid.
[153] Oreopoulos and Petronijevic, 2017.
[154] Page and Gehlbach, 2017

college advisers and administrators. For the sample of students that had committed to attending Georgia State, the texting program increased enrollment there by 3.3 percentage points.[155]

5.4 Mindset Interventions

Finally, several recent programs have been experimentally evaluated that use technology in implementing "mindset interventions"—programs that attempt to improve education outcomes by cultivating "attitudes, beliefs, and dispositions about school and learning that are associated with positive academic outcomes and school success,"[156] often through brief reading and writing exercises. During these interventions, students are typically encouraged to think about setbacks, or feeling out of place, or lack of motivation from a different perspective. The idea is that if students recognize setbacks and mistakes as an important part of the learning process, they can keep trying and have a greater chance of success. Similarly, if students recognize the feeling of not fitting is as a normal part of the transition process, they may be more likely to keep making efforts and eventually feel socially integrated, which in turn will raise the chances that they will complete college.

Previous experiments have shown promise for these interventions in in-person settings, but these next experiments extend them using technology, which allows for the provision of these exercises to students online, at virtually no cost other than a small amount of participating students' time. Of the 12 online mindset intervention studies we identified, a majority showed positive results.[157] In one of the largest-scale studies to date, a sample of nearly 10,000 students

[155] Ibid.

[156] Snipes et al., 2012; Dweck, 2006.

[157] Good et al., 2003; Morisano et al., 2010; Paunesku et al., 2015; Unkovic et al. 2016, Yeager et al., 2013, Yeager et al., 2014, Yeager et al., 2014; Yeager et al., 2016; Yeager et al., 2017; and Yeager et al., 2017 found positive results. Bursztyn and Jensen, 2015; Forsyth et al., 2007 found negative results.

transitioning from high school to college across diverse contexts were given multiple variations of internet-based "lay theory" interventions that aimed to prepare the students to encounter adversity and help them to understand that this is a natural part of the college transition process. These interventions showed positive impacts on a variety of outcomes relating to persistence, with authors estimating that the gains could mean a 31-40 percent reduction in the gap between "advantaged" and "disadvantaged" students.[158] Mindset interventions have been shown to improve high school performance as well: another program delivered exercises similar to the lay theory units described above to a treatment group within a sample of 1,594 students from 13 public, private, and charter high schools across the U.S. This study found GPA improvements and a positive impact of 6.4 percentage points on achieving satisfactory grades in core classes among the third of students classified as "at risk" for dropping out of high school.[159]

5.5 Looking Forward

As has been shown to be the case within a variety of policy sectors, evidence consistently shows that technology-enabled behavioral interventions can have meaningful, if modest, impacts on a variety of education-related outcomes, often at extremely low costs. Moving forward, several tasks will be important to advance the policy-relevant research. For one, many of the interventions discussed in this section have relied on text messages, and the effectiveness of text messages may in part rest on the fact that they are still somewhat novel. It may be that people become less responsive to text messages as they grow increasingly inundated with messages and pay less attention to them. It is thus essential for policy researchers to explore more specific

[158] Yeager et al., 2016.
[159] Paunesku et al., 2015.

lessons about why particular types of text campaigns work well, so as to facilitate lessons that may be explored across different communications platforms.

For the time being however text message-based programs may exert significant impact at low cost, and explorations should continue as to which points in the education life cycle are most responsive to text-based nudges and information channels (e.g., as in the school-to-parents text notifications discussed above). Evidence discussed in this section also highlights the importance of personalization and customization of messaging, but such customization can be costly. Research should thus also continue to explore the most effective ways to integrate artificial intelligence and machine learning into these interventions, as in the AdmitHub example discussed above. Finally, the research on large-scale internet-based mindset interventions remains in its infancy, but given the substantial results that have been found at scale thus far, learning more about which approaches to mindset changes are most effective, and in which contexts.

Table 3

Author	Intervention	Data Source	Sample	Findings	Education Setting
Balu, Porter, and Gunton (2016)	Automated text messages to parents of high school students informing about absence	School administrative data on student absences	3,957 New York City high school students	No effect found	High school
Barr, Bird, and Castleman (2016)	Text messaging campaign prompting loan applicants at a large community college to make informed and	School administrative data on student demographics, socioeconomic status, academic information, and	2,807 community college loan applicants in	(1) Students reduced their unsubsidized loan borrowing, a result driven by those with low financial literacy levels and high debt. (2) Short-term academic effects suggest that the intervention may also	Post-secondary

	active borrowing decisions	financial aid disbursement	Baltimore County	have led marginal students to withdraw one semester earlier than they otherwise would have.	
Bergman (2015)	Automated texts to parents about performance	School administrative data on assignment completion, work habits, cooperation, attendance and test scores; parent and study surveys	462 students in grades 6-11 in Los Angeles	(1) Positive effects .19 SD high school GPA increase (2) 7.5 percentage point decrease of missing final exam project (3) .21 SD increase for math standardized exam scores (4) Null for English	Middle & High School
Bergman (2016)	Learning Management System (parents have access to an online portal with child's classes, grades, assignments, etc)	Deidentified data from a Learning Management System (LMS) company, NCES Common Core Data, decile performance ratings constructed by GreatSchools	15 US school districts operating learning manageme nt company; two-stage experiment providing families their account information in 59 schools across three districts.	(1) A quarter of parents ever use it (2) Adoption follows an S-shape (3) Significant spillovers occur along intensive but not extensive margins (4) There is evidence student grades improve as a result.	Middle & High School
Bergman and Chan (2017)	Automated texts to parents about performance	Administrative data, gradebook data, survey data, and texting data	22 middle and high schools in Kanawha County Schools in West Virginia	(1) Reduces course failure by nearly 40 percent. (2) GPA increases by about .10 of a point for middle school students and .25 of a point for high school students. (3) Treatment group students attend 17 percent more classes. (4) No improvements in state math and reading scores. (5) .10 SD increase on in-class exam scores.	Middle & High School
Bergman, Denning, and Manoli (2016)	E-mails and letters to potential/ prospective/current college students on financial aid/incentives	ApplyTexas basic demographic data, THECB administrative data on all students in public universities and community colleges in the state of Texas, data on who	1,042, 303 students who had applied to any public Texas college or university using the ApplyTexa	No effects found	Post-secondary

		opened the emails researchers sent	s.org portal.		
Bergman, Edmond-Verley, and Notario-Risk (2016)	Community-based organizations provided regular information to families about their child's academic progress in one arm and supplemented this with home visits on skills-based information in a separate arm	District administrative data on math and reading test scores, GPA, and attendance, program data from implementing partners	1,120 families from 3 participating schools in an urban, Midwestern school district	(1) Math and English test scores improved for the treatment arm with home visits (2) There are large effects on retention for both groups during the year, though learning gains tend to accrue for students with average-and-above baseline performance and students at the lower-end of the distribution appear marginally retained.	Middle & High School
Bergman and Hill	Publishing teacher ratings online	LAUSD data on identifiable teacher names linked to de-identified student test scores, LA Times value added scores	3,089 teachers in Los Angeles	(1) High-performing students sort into classrooms with highly-rated teachers (2) Conditional on publication, ratings labels induce sorting as well as teacher attrition: low-rated teachers teach lower-performing students and are more likely to leave the district in subsequent years relative to higher-rated teachers (3) There is no effect of publication on test scores	Grade 3-5 teachers
Bergman and Rogers (2016)	Text message to parents regarding their child's academic performance, including grades, upcoming tests and missing assignments	District administrative records and collected data on parents and students daily activity in the "parent portal"	6,976 students in 12 US schools	(1) ITT estimates indicate that being assigned to the Opt Out group increased grades by 0.06 SDs for Term 3 and in 0.04 SDs for Term 4 (2) Overall, grades increased by 0.05 SDs in Terms 3 and 4, with a 5 percent significance level.	Middle & High School
Bettinger et al. (2012)	H&R Block study--help with FAFSA during tax filing	Researchers linked their final sample to data from three sources: the DOE, the Ohio Board of Regents (OBR), and the National Student	4,187 individuals from the dependent sample, 868 seniors in high school (main dependent sample);	(1) The combined assistance and information treatment substantially increased FAFSA submissions and ultimately the likelihood of college attendance, persistence, and aid receipt. (2) High school seniors whose parents received the treatment were 8 percentage points more likely to have	Post-secondary

		Clearinghouse (NSC)	independent sample of 15,874 individuals, further separated into those without prior college experience (9,228) and those with prior college experience (6,646) in Ohio and Charlotte, North Carolina	completed two years of college, going from 28 to 36 percent, during the first three years following the experiment.	
Bird et al. (2017)	Nudges for early FAFSA filing through Common App	Student-level college application data provided by Common Application and college enrollment data provided by the National Student Clearinghouse	454,243 US high school seniors who had registered with the Common Application	Positive effect for treatment arm that involves concrete planning prompts	Post-secondary
Bursztyn and Jensen (2015)	Two interventions: 1. performance leaderboard into computer-based high school courses 2. Complimentary access to an online SAT preparatory course. Sign-up forms differed randomly across students only in whether they said the decision would be kept private from classmates.	Study 1: Data for the universe of questions answered, with each student uniquely identified by an ID code Study 2: student survey; data on whether students actually logged into the system later to activate their accounts	Study 1: 5,000 students across more than 100 schools in Los Angeles. Study 2: 26 classrooms across the four schools in Los Angeles, with a total of 825 students	(1) 24 percent performance decline. The decline appears to be driven by a desire to avoid the leaderboard. (2) In nonhonors classes, sign-up was 11 percentage points lower when decisions were public rather than private. Honors class sign-up was unaffected.	High School

Castleman et al. (2012)	Providing college counseling to low income students during the summer	School administrative data, college/ transition counselor interaction logs, National Student Clearinghouse data	162 senior students across 7 high schools in Providence, Rhode Island	(1) Substantial improvements in both the rate and quality of college enrollment (2) Students in the treatment group were 14 percentage points more likely to enroll immediately in college and 19 percentage points more likely to keep the postsecondary plans they developed during senior year.	High School
Castleman and Meyer (2016)	A text messaging campaign to provide lower-income college students with simplified information, encouragement, and access to one-on-one advising	Data from Signal Vine, the texting platform with whom WVHEPC contracted to send the messages, dataset provided by WVHEPC, which listed all students who matriculated into a state public university or community college	1,198 students in West Virginia	Students participating in the texting campaign tend to complete more freshman year credits	Post-secondary
Castleman and Page (2015)	Text messages to reduce summer melt	College enrollment data from the National Student Clearinghouse	12,676 recent high school graduate in Dallas, Boston, and Philadelphia	Increased enrollment among students with less access to college-planning supports and who were not as far along with their college planning at the completion of high school.	Post-secondary
Castleman and Page (2016)	Text message to improve FAFSA re-filing for sophomore year	uAspire administrative data, data from the text messaging platform utilized, uAspire student interaction logs, National Student Clearinghouse data	808 first-time college freshmen in Massachusetts	Positive effects	Post-secondary
Castleman and Page (2016)	Text messages to improve enrollment tasks	uAspire administrative data, data from the text messaging platform utilized, National Student Clearinghouse data	3,906 high school graduate in Boston, Lawrence, and Springfield, Massachusetts	Positive effects (although no additional benefit from including parents on nudges)	Post-secondary

Chande et al. (2015)	Texting motivational messages and organizational reminders to students, with messages drawing on insights from behavioral economics	College administrative data on student attendance	1,179 students in England	Simple text messages reduce the proportion of students that stop attending by 36 percent and lead to a 7 percent increase in average attendance relative to the control group.	Adult learners
Darolia (2016)	Letter e-mailed to students regarding financial aid	Administrative data on loan disbursement	Approximately 10,000 college students in the Midwest	No effects found overall. However, some key student subgroups changed their borrowing in response to the letter, particularly those with low GPAs.	Post-secondary
Doss et al. (2017)	READY4K! Continuation into kindergarten with additional differentiated/personalized treatment arm	Teacher survey, parent survey, and scores from Fountas and Pinnell Benmark Assessment System	794 kindgergarten students and families in California	(1) Children in the differentiated and personalized program were 50 percent more likely to read at a higher level ($p<0.01$) compared to the general group (2) Parents reported engaging more in literacy activities by 0.31 SDs ($p<0.01$) compared to the control group (3) No effects detected for other treatment arm	Early childhood
Forsyth et al. (2007)	Self-esteem bolstering intervention	Primarily score on a final examination	90 US college students	The D and F students got worse as a result of self–esteem bolstering and students in the other conditions did not change.	Post-secondary
Fryer (2016)	Students were provided with free cellular phones and daily information about the link between human capital and future outcomes via text message in one treatment and minutes to talk and text as an incentive in a second treatment	Administrative data from all schools in OKCPS; post treatment student survey	1907 students in sixth and seventh grades in Oklahoma	(1) Students' reported beliefs about the relationship between education and outcomes were influenced by the information treatment (2) There were no measurable changes in student effort, attendance, suspensions, or state test scores, though there is evidence that scores on college entrance exams four years later increased.	Middle School

Good et al. (2003)	Seventh-grade students in the experimental conditions were mentored by college students through an email platform who encouraged them either to view intelligence as malleable or to attribute academic difficulties in the seventh grade to the novelty of the educational setting.	Math and reading test scores	138 seventh grade students in Texas	(1) Females in both experimental conditions earned significantly higher math standardized test scores (2) The students—who were largely minority and low-income adolescents—in the experimental conditions earned significantly higher reading standardized test scores.	Middle School
Harackiewicz et al. (2012)	The three-part intervention consisted of two brochures mailed to parents and a Web site, all highlighting the usefulness of STEM courses	Primarily student surveys which measured success expectancies and initial and post treatment interest in science	188 high school students in Wisconsin	Students whose parents were in the experimental group to take, on average, nearly one semester more of science and mathematics in the last 2 years of high school, compared with the control group	High School
Hurwitz et al. (2015)	Texting program to promote learning engagement of Head Start parents	Parent survey	253 Midwestern parents	Parents who received the service engaged in more learning activities; this was particularly true of fathers and parents of boys.	Early Childhood
Kraft and Dougherty (2013)	Parents texted on student behavior/performance	Teacher surveys; teacher communication logs; student interviews; student demographic data	140 rising sixth and ninth grade students in Boston, Massachusetts	(1) On average, teacher–family communication increased the odds that students completed their homework by 40 percent, decreased instances in which teachers had to redirect students' attention to the task at hand by 25 percent and increased class participation rates by 15 percent	Middle & High School
Kraft and Monti-Nussbaum (2017)	Parents texted to encourage to engage in activities to counteract summer learning loss	Scores from Standardized Test for the Assessment of Reading (STAR) and the Strategic Teaching and Evaluation of Progress (STEP), measures of parent engagement, parent survey	183 US families	Effects on reading comprehension are concentrated among 3rd and 4th graders with effect sizes of .21 to .29 SDs, more than compensating for summer learning loss	Elementary

Kraft and Rogers (2015)	Parents texted on student behavior/performance	School administrative records, teacher surveys, student surveys	435 high school students in Northeastern United States	(1) Messages decreased the percentage of students who failed to earn course credit from 15.8 percent to 9.3 percent—a 41 percent reduction (2) This reduction resulted primarily from preventing drop-outs, rather than from reducing failure or dismissal rates.	High School
Ksoll et al. (2014)	Innovative mobile phone-based adult education program (Cell-Ed)	Reading assessment scores, student household characteristics survey, interviews with students, Cell-Ed real time usage data	70 adult learners in Los Angeles	(1) Significantly increased students' basic and broad reading scores, equivalent to a 2-4 year increase in reading levels over a four-month period (2) The program also increased participants' self-esteem by 7 percent.	Adult learners
Mayer et al. (2015)	Texting program to promote learning engagement of Head Start parents	Time stamped data from the reading app, parent surveys	169 parents in Chicago	(1) Increased usage of the reading application by one SD after the six-week intervention. (2) Evidence suggests that the large effect size is not accounted for by the information component of the intervention and that the treatment impact was much greater for parents who are more present-oriented than for parents who are less present-oriented.	Early Childhood
McGuigan, McNally, and Wyness (2012)	Information campaign about the costs and benefits of pursuing post compulsory education	Student surveys	6,614 Year 10 students in England	Students with higher expected net benefits from accessing information are more likely to avail themselves of the opportunity presented by our experiment	High School
Meuwissen et al.	Text2Learn, a mobile phone texting program for low income parents of preschoolers.	Parent survey	110 parents in Minnesota	(1) Parents reported engaging in more literacy activities with their children after receiving the texts, and appreciated getting reminders about activities (2) They did not report increased use of community resources, such as libraries, or changes in attitudes about literacy.	Early Childhood

Morisano et al. (2010)	Goal-setting program	Student surveys, university transcripts	85 college students in Canada	After a 4-month period, students who completed the goal-setting intervention displayed significant improvements in academic performance compared with the control group.	Post-secondary
Oreopoulos and Dunn (2013)	3-minute video and opportunity to use financial aid calculator	Student surveys	1,616 high school students in Canada	Positive effects on PSE-related benefit-cost	High School
Oreopoulos and Petronijevic (2017)	Text-based advising	Interaction log, student survey, college administrative data on course grades and GPA	4,900 first year college students in Canada	No effects found	Post-secondary
Oreopoulos and Ford (2016)	Application assistance is incorporated into the high school curriculum for all graduating seniors at low-transition schools	Ontario Ministry of Education administrative data which included demographic data, high school performance data, and post-secondary enrollment data	86 schools in Canada	(1) Increased application rates from 64 to 78 percent, college enrollment increased the following school year by 5.2 percentage points with virtually all of this increase in two-year community college programs (2) The greatest impact was for students who were not taking any university-track courses in high school: the application rate for these students increased by 24 percentage points with a nine percent increase in two-year college enrollment	High School
Page, Castleman, and Meyer (2016)	FAFSA texting program	Administrative data on the status of students' FAFSA submissions, district administrative data in Texas, administrative data from ApplyTexas portal, National Center for Education Statistics Common Core of Data (CCD) for Delaware; text messaging records	Texas: 66 high schools serving over 17,000 high school seniors; Delaware: 4,095 high school seniors	(1) The intervention substantially increased enrollment among students with less access to college-planning supports and who were not as far along with their college planning at the completion of high school.	High School

Paunesku et al. (2015)	Growth-mindset and sense-of-purpose interventions	Student transcripts and psychological measures	1,594 US students in 13 geographically diverse high schools	Among students at risk of dropping out of high school (one third of the sample), each intervention raised students' semester grade point averages in core academic courses and increased the rate at which students performed satisfactorily in core courses by 6.4 percentage points	High School
Rogers and Feller (2016)	Parents of high-risk, K-12 students received one of three personalized information treatments throughout the school year	Daily attendance data	28,080 households across 203 US schools	(1) The most effective versions reduced chronic absenteeism by 10 percent, partly by correcting parents' misbeliefs about their students' total absences (2) The intervention reduced student absences comparably across all grade levels, and reduced absences among untreated cohabiting students in treated households.	K-12
Unkovic et al. (2016)	Personalized emails encouraging graduate students to apply for a conference	Conference registration information, student survey	3,945 US graduate students	Robust, positive effect associated with this simple intervention and suggestive evidence that women responded more strongly than men. However, women's conference acceptance rates are higher within the control group than in the treated group. This is not the case for men, female applicants in the treated group solicited supporting letters at lower rates.	Post-secondary
Yeager et al. (2013)	6-session intervention that taught an incremental theory (a belief in the potential for personal change).	Student survey, school administrative data which included demographic and academic information	230 ninth and tenth grade students in California	Compared to no-treatment and coping skills control groups, the incremental theory group behaved significantly less aggressively and more prosocially 1 month post intervention and exhibited fewer conduct problems 3 months post intervention.	High-School
Yeager et al. (2014)	A malleable (incremental) theory of personality—the belief that people can change.	Student surveys, scores from the Cyberball procedure on social exclusion, scores from 10-item Perceived Stress Scale, physical health	158 ninth grade students in Californian	The incremental theory group showed less negative reactions to an immediate experience of social adversity and, 8 months later, reported lower overall stress and physical illness. They also achieved better academic performance over the year.	High School

		measures, and end of term core course grades			
Yeager et al. (2014)	Promoting a prosocial, self-transcendent purpose	*Study 1:* Primarily student surveys on behavior; National Student Clearinghouse data; *Study 2:* STEM GPA; *Study 3:* student exam answers; *Study 4*: Primarily student surveys on behavior	*Study 1:* 1,364 US high school seniors; *Study 2:* 338 US ninth grade students; *Study 3*: 89 college students; *Study 4:* 429 US college students	Those with more of a purpose for learning also persisted longer on a boring task rather than giving in to a tempting alternative and, many months later, were less likely to drop out of college. A brief, one-time psychological intervention promoting a self-transcendent purpose for learning could improve high school science and math grade point average (GPA) over several months.	High School
Yeager et al. (2016) Design	Working to scale previous interventions: Qualitative inquiry and rapid, iterative, randomized "A/B" experiments were conducted with 3,000 participants to inform intervention revisions for this population.	*Study 1:* Primarily student surveys and behavioral measures *Study 2:* Student GPA and behavioral measures	*Study 1:* 7,501 ninth grade US students; *Study 2:* 3,676 ninth grade US students	The intervention was an improvement over previous versions in terms of short-term proxy outcomes and it improved 9th grade core-course GPA and reduced D/F GPAs for lower achieving students when delivered via the Internet	High School
Yeager et al. (2016)	"Lay theory" intervention	*Study 1:* Primarily student surveys and National Student Clearinghouse enrollment data; *Study 2:* Primarily student surveys; *Study 3:*Primarily student surveys	*Study 1:* 584 US high school seniors; *Study 2:* 7,335 US first year college students; *Study 3:* 1,592 US college students	Increased full-time enrollment rates, improved grade point averages, and reduced the overrepresentation of socially disadvantaged students among the bottom 20 percent of class rank. The interventions helped disadvantaged students become more socially and academically integrated in college.	High School/Post-Secondary
Yeager et al. (2017)	A program teaching a growth mindset of intelligence	Behavioral assessments and mindset assessments	14,866 US ninth grade students	(1) Although program effects were positive across schools, there was (modest) heterogeneity, suggesting that sampling from different subsets of schools would have yielded different conclusions. (2) Overall, results suggest growth	High School

				mindset approaches may be useful in preparing learners for the future economy.	
York and Loeb (2014)	Text messaging program to nudge preschool parents to engage in literacy activities with children	The READY4K! enrollment form, an end of-year survey of parents, an end-of-year survey of teachers, SFUSD's administrative records, student scores on the district's early literacy assessment	440 families in California	Increases engagement in literacy activities 0.22-0.34 SDs and parental involvement at school by 0.13-0.19 SDs; learning gains of 0.21 to 0.34 SDs	Early Childhood

6. Online Courses

Since their emergence during the 1990s, online courses have come to constitute a sizeable presence within the education field. By 2013, over a third of U.S. college students had taken an online course at some point during their college career[160] and more than 11 percent were enrolled in entirely online programs.[161] The rise of online learning bears heavily on policy issues relating to educational equity, since two key justifications for the proliferation of online education have been its promise of improving access and reducing costs. Moreover, at least at the post-secondary level, students in online programs tend to face disproportionate educational disadvantages. For instance, data from the National Postsecondary Student Aid Study's 2010/2011 representative survey indicates that "online students are older, have lower levels of

[160] Bettinger et al., 2014, citing Allen and Seaman, 2013.
[161] Deming et al., 2015.

parental education, are more likely to be single parents themselves, and are more likely to be working full-time while enrolled in school than are other college students."[162] So how does online education perform in terms of access, learning, and other important outcomes?

Online courses have, over the past several years, coalesced into two broad categories. First, what we refer to as *conventional online courses* represent an online extension of the "distance learning" or "correspondence course" format, an approach which has a long history in higher education.[163] These courses are typically offered as part of a degree program that consists entirely of online courses, or that includes online, face-to-face, or blended[164] courses. Second are Massive Open Online Courses (MOOCs). Unlike conventional online courses, MOOCs are typically offered free of charge and are not part of official degree programs. They broadly consist of "structured and sequenced teacher-led activities (e.g., videos, readings, problem-sets) coupled with online assessments and usually some venue for student interaction such as a discussion forum."[165] Between 2012 and 2015, MOOCs saw enrollment rates exceeding 25 million.[166] While conventional online courses and MOOCs developed to serve largely separate purposes, the lines between them are becoming blurred. For instance, MOOC companies have increasingly offered certification programs for a fee such as MicroMasters programs,[167] and MIT has even launched a MOOCs program that will lead to a traditional master's degree.[168]

Nonetheless, within the present environment, conventional online courses to date have followed mostly distinct pathways, and the research has clustered accordingly. Experimental

[162] Ibid.
[163] Means et al., 2009.
[164] The term blended takes on different meanings in different contexts within the ed-tech literature—in this case, we use the term to refer to a single course that has both online and face-to-face components.
[165] Hodges et al., 2016.
[166] Kizilcec et al., 2017.
[167] MicroMasters, https://www.edx.org/micromasters.
[168] MIT announces MITx Micromasters program in development economics, with path to full master's degree, http://news.mit.edu/2016/mitx-micromasters-program-development-economics-masters-degree-1205.

research on conventional online courses has compared online against face-to-face courses to judge the extent to which the former improves access and can act as a viable substitute for face-to-face education. While researchers are also interested in the effects of MOOCs on education, it is less clear what to compare them to since they generally do not substitute for face-to-face courses that students would otherwise take. Experimental research on MOOCs up to this point has thus focused primarily on whether and how a range of behavioral interventions can improve MOOC completion rates and extend coverage to disadvantaged groups. In the remainder of this section, we first discuss the experimental evidence on conventional online courses, and then turn to a discussion of studies on MOOCs.

6.1 Conventional Online Courses

Online courses build on a tradition of correspondence courses that has existed for over a century within the higher education field.[169] As early as the latter 1800s, institutions like the University of Chicago and the University of Wisconsin were teaching faraway students via the postal service.[170] Educators and entrepreneurs brought online college courses and degree programs to market beginning in the 1990s, but proliferation expanded rapidly after a 2006 decision to end a regulation that had limited federal aid money for institutions conducting more than half of their coursework via correspondence.[171] Some institutions offer both online and face-to-face instruction, while others offer online courses exclusively. While a growing mass of

[169] Means et al., 2009.
[170] Deming et al., 2012 citing Watkins, 1991.
[171] Deming et al., 2015.

selective universities offers online programs, online education remains heavily dominated by large, for-profit colleges[172] like University of Phoenix and Strayer University.[173]

How might online courses add value to education? One justification for online courses is that online courses in many contexts may be much less expensive to implement than face-to-face courses, so that if "Internet-based classes are at least reasonable substitutes for live lecture classes, then the use of Internet-based classes could be a cost-effective method of combating increased fiscal constraints."[174] A second is that they can expand access by allowing people to take courses that would not otherwise be possible or worthwhile for them to take, for instance because of geographic location, work or family obligations during class hours, or disabilities.[175] And online courses may allow students more flexibility in accessing course materials at the most convenient times, and in spending more time on content that they are struggling with and less on content that they have mastered.[176]

Educators and researchers have also pointed out potential drawbacks of online courses. The flipside of online courses' flexibility is that students who do better with externally-induced structure may be more likely to face time management issues than they would for a face-to-face class, and may thus fall behind. [177] It is also possible that too large a shift toward online courses could take away opportunities for networking and interaction that arise more naturally in face-to-face environments.[178] More generally, some educators and researchers believe that a valuable

[172] Deming et al., 2012.
[173] Burnsed, 2010. https://www.usnews.com/education/online-education/slideshows/10-largest-online-schools
[174] Figlio et al. 2013; see also Cowen and Tabarrok, 2014; Means et al., 2009.
[175] Goodman et al., 2016; Means et al., 2005; Poirier and Feldman, 2004.
[176] Figlio et al., 2013.
[177] Ibid, 764.
[178] Sleeter, 2014. https://www.insidehighered.com/blogs/higher-ed-beta/meaningful-interaction-online-courses

element of the teaching process is lost when the face-to-face dimension is reduced or eliminated.[179]

We identified nine experimental studies examining the effects of conventional online courses. Of these, seven RCTs[180] compared online and face-to-face delivery (or various gradations in between) of particular courses, one RDD[181] tested the extent to which offering an online degree option increased enrollment, and one audit RCT tested whether employers distinguished between online and face-to-face degree when selecting resumes to follow up on.[182]

First, to what extent does the evidence suggest that Internet-based classes can match or exceed learning outcomes from face-to-face classes? While a great deal more exploration and replication would be needed to draw robust conclusions, the studies reviewed here are consistent with the hypothesis that, without some degree of face-to-face teaching, learning outcomes may suffer, leading to (albeit small) sacrifices in test scores for fully online courses relative to face-to-face courses. In contrast, blended learning environments—meaning, in this case, courses that have both a face-to-face component and an online component—have not yet been found to significantly underperform purely face-to-face courses in studies meeting our methodological criteria. So, while evidence at this point would not back substantial shifts toward fully online courses, it does indicate that switching courses from fully in-person to blended could decrease costs without negatively affecting quality.

[179] Ibid.

[180] Alpert et al., 2016; Bowen et al., 2014; Figlio et al., 2013; Heppen et al., 2012; Joyce et al., 2015; Keefe, 2003; Poirier and Freeman, 2004. Zhang, 2005. Another experiment, reported by Snipes et al., 2015 and included in **Table 2**, experimentally evaluates a middle school summer math program that includes an hour daily use of Khan Academy, but since the study compares the program as a complete package against a control group that does not attend any program, the study cannot identify independent effects of the online component.

[181] Goodman et al., 2016.

[182] Deming et al., 2016

The first full-scale field experiment to compare face-to-face with online courses took place in an introductory economics course at a major research university, with a sample of over 300 students.[183] The course was identical for all students, but some students were provided access to online video lectures, while others attended these lectures in person. The study finds that students in the in-person group show higher outcomes, but that the differences are relatively small—around 3 percentage points on the midterm and about 2.5 percentage points on the final. In actual university settings however, the choice will not necessarily be between courses that are entirely face-to-face or entirely online—instead, the two are often mixed into blended courses. Two subsequent experiments studied blending learning environments of this sort. One compared outcomes for a statistics course in which one group received three hours per week of face-to-face instruction time, while another group received only one hour of instruction time but additional internet-based exercises. The second experiment tested the effects of reducing face-to-face in an economics course where all students also had access to online resources. Neither experiment found significantly better outcomes to be associated with more in-person class time in a blended learning context.

Finally, the most comprehensive study in this strand of the literature—the only one to test fully online, blended, and fully face-to-face courses within the same experiment—found results consistent with each of the above.[184] Here, the authors test the impact in an economics course of two treatments arms—one purely online and one blended—along with a fully face-to-face

[183] Keefe, 2003 conducted a related study in an undergraduate business course and comes up with results that are in the same direction as Figlio et al., 2013 but this study had a sample of only 35 students (with students in face-to-face classes performing better). Another study conducted in a university psychology class with a sample of only 23 students found opposite results, with students in the online version performing marginally better than those in a face-to-face group. Zhang, 2005 and Zhang et al., 2006 run experiments on 155 and 138 undergraduates respectively and find that interactive online modules outperform non-interactive online modules and face-to-face sessions, but the context is single-session lab experiments rather than a field experiment with actual classes.

[184] Alpert et al., 2016.

control group in a single experimental context. This study finds that students in the purely online version of the course do not perform as well as those in the purely face-to-face group, while outcomes for the blended treatment group are not statistically different from the control.[185]

The majority of research on online courses has been conducted in post-secondary settings, but educators have increasingly attempted to leverage online learning in middle and high school environments as well. We identified one experimental study that tested the effectiveness of online summer credit recovery courses relative to face-to-face courses for students who had failed freshmen algebra.[186] The study was conducted in 15 high schools in the Chicago Public Schools system with the lowest rates of students passing freshmen algebra, with a sample of nearly 1400 students across two cohorts. The hope was that the online course would provide "a more individualized, interactive experience" prompting students to "be more engaged and more likely to persist in the course." However, students in the face-to-face course outperformed those in the online course. Suggestive evidence from the study indicates that one significant reason was that teachers in the face-to-face course were better able to flexibly incorporate a range of topics, and thus were better able to accommodate and engage the students.[187]

To what extent do online courses increase access to education for those for whom it may not be feasible to pursue a face-to-face degree? One of the main justifications for the potential usefulness of online courses is that they can improve access to degree programs for populations who otherwise might have trouble accessing them. We identified only a single study fitting our criteria that addressed this question. Specifically, the researchers relied on an RDD design to

[185] Ibid.
[186] Heppen et al., 2012.
[187] Ibid.

reveal that prospective students applying to Georgia Tech's online master's program in computer science who were just above an admissions cutoff (which was not known to the applicants) for the online version of the program were 20 percentage points more likely to end up in any postsecondary program than those just below the cut-off.[188] The strongest effects were observed among mid-career prospective students, who otherwise may have chosen not to complete a degree at all had the online program not been offered to them.[189] Another recent experiment, however, finds that "a business bachelor's degree from a for-profit online institution is 22 percent less likely to receive a callback than one from a nonselective public institution."[190] But the design does not allow for untangling the effect of the education medium (online vs. face-to-face) from the institution's for-profit/not-for-profit status. And even if employers do place a penalty on online degrees, this may change in the coming years given the ongoing expansion of the online education sector.

6.2 Massive Open Online Courses (MOOCs)

The term MOOC was first used in 2008 by media theorists George Siemens and Stephen Downes for a course they taught at the University of Manitoba entitled "Connectivism and Connected Knowledge," with 25 students participating in face-to-face sessions at the university, and content broadcasted to 2,300 additional students via the Internet.[191] In the subsequent decade, MOOCs have proliferated rapidly, with hundreds of courses offered and hundreds of thousands of students enrolled worldwide.[192] Like online courses, educators and education

[188] Goodman et al., 2016.
[189] Ibid.
[190] Deming et al., 2016.
[191] Greene et al., 2015; see also Cormier and Siemens, 2010.
[192] Ibid.

policymakers saw in MOOCs the potential to decrease costs and increase access.[193] Because MOOCs are generally "open," they have the potential to reach exponentially more students in a much more diverse range of contexts than can conventional online courses granted for credit. However, because MOOCs usually do not build toward a degree and may or may not be valued on the labor market, it is less clear what, if any benefits, MOOCs may bring beyond the value of the educational content they impart.

What has been the effect of MOOC proliferation? Observational research has found that expectations that MOOCs will "democratize education" have been overblown and that, although MOOCs have offered the opportunity for many disadvantaged individuals to access high-quality educational content, enrollment and success rates are highly skewed toward advantaged populations. MOOCs may even "exacerbate rather than reduce disparities in educational outcomes related to socioeconomic status."[194] But overall impact is difficult to evaluate. People may take MOOCs for a wide variety of reasons, from practicing skills for school or work to fun and personal interest. Because MOOCs broadly speaking lack a clear counterfactual in that there is no single function they seek to fulfill or institution they attempt to substitute for, no clear experimental evidence has yet emerged on their overall impact, although this is likely to change over the next several years given the outpouring of interest. Nonetheless, MOOCs are being given to millions of students each year, and researchers have begun to delve experimentally into questions of how MOOC usage can be improved for interested students. In fact, MOOCs lend themselves well to low-cost RCTs, among other types of data generation and analysis.[195]

[193] Ibid.
[194] Hansen and Reich, 2015.
[195] Lamb et al., 2015.

A growing body of studies has thus evaluated the effects of interventions aimed at improving MOOC effort, persistence, and completion. For instance, MOOCs face very low completion rates—"few users actually complete the class".[196] These low rates in themselves do not necessarily signal a problem—many students enroll with no intention of completing the course, and students may generally be getting what they wanted or needed from the MOOCs even if they are only accessing bits and pieces. But low rates may at least in part reflect missed learning opportunities that could be avoided with modifications to the MOOC platform.[197] Interventions aiming to improve student MOOC effort have generally followed the approaches of the behavioral and mindset interventions discussed in the preceding section. The studies have typically found improvements, with seven of the nine studies evaluating these interventions finding positive effects from at least one treatment arm.[198]

How might students be prompted to increase effort and persistence? One approach adopted from the behavioral economics literature has been the model of "social comparison" interventions—programs that inform students of their performance relative to other students. The behavioral economics literature suggests that social comparisons may drive individuals to try harder to excel. Two recent RCT studies[199] found that social comparison interventions can improve MOOC performance and completion, although one of these[200] found significant effects only when framed "negatively" (i.e., when target students were informed of how many students had outperformed them rather than how many students they had outperformed).

[196] Banerjee and Duflo, 2014.
[197] Ibid.
[198] Banerjee and Duflo, 2014; Davis et al., 2017; Kizilcec et al., 2014; Kizilcec et al., 2017; Lamb et al., 2015; Martinez, 2015A; Martinez, 2015B; Patterson, 2015; Yeomans and Reich, 2017. Banarjee and Dufo, 2014 and Kizilcec et al., 2014 do not find positive impacts.
[199] Davis et al., 2017; Martínez, 2014.
[200] Martinez, 2014.

Even if fully motivated to succeed in a course, MOOC students may struggle with time management issues and, in particular, the temptation to procrastinate. Procrastination may be a particularly acute temptation for MOOC students since they are not being directly observed by an instructor. One study that attempted to address problems of procrastination found that a commitment device that encouraged students to commit to limitations on time spent on distracting internet sites increased the likelihood of completion by 40 percent and grades by 0.29 standard deviations, while treatment arms that reminded students how much time they were spending on these websites or blocked them while on the course page showed no significant effect.[201] Relatedly, sending MOOC students a "planning prompt" improved course completion by 29 percent.[202]

Many educators firmly believe that discussion and interaction is a central component of education. But because MOOCs have thousands of students who generally access content at different times, regular discussions of the types that occur in classroom are rarely feasible. MOOC designers have attempted to at least partially address this problem by building discussion forums into MOOCs, but participation is often relatively low. Two experimental studies have evaluated efforts to increase participation in discussion forums. One study found insignificant or negative impacts from an email prompt (depending on the content of the email),[203] while another found positive impacts on forum participation from asking participants to fill out a self-evaluation about forum participation.[204]

Another friction preventing efficient and equitable use of MOOCs may be "social threat," the tendency of individuals—typically from marginalized social backgrounds—to "suffer from

[201] Patterson, 2015.
[202] Yeomans and Reich, 2017.
[203] Kizilcec et al., 2014.
[204] Lamb et al., 2015.

the cognitive burden of wrestling with feeling unwelcome while trying to learn and, therefore, underperform."[205] Social identity threat has been shown to impair learning in a variety of ways. One recent set of RCTs evaluations tested the effects of writing exercises aimed at reducing social identity threat and found them to be effective in increasing persistence and completion among MOOC students from developing countries.[206] While this study focused on closing the gap between students from developed and developing countries, related interventions could also plausibly reduce social identity threat-driven gaps between advantaged and marginalized populations within the developed world.

6.3 Looking ahead

The online learning field is changing quickly, and new models that do not easily fit into the categories discussed here are springing up. For one, websites that offer more independent standalone modules--which allow for easier picking and choosing of content, and use in supplementing other classes—are becoming increasingly important. The iconic website in this category is Khan Academy, which is currently undergoing several evaluations. Also popular in this space has been BrainPOP, which provides instructors with an expansive library of educational videos intended to be fun and engaging.

Another new development has been the rise of quasi-formal certification schemes, like NanoDegrees and MicroMasters, as alluded to above. These are certifications granted for completing sets of courses that are not formal degrees in the sense of college degrees, but that programs' designers hope will increase their legitimacy and acceptance as real skill creators.

[205] Kizilcec et al., 2017.
[206] Ibid.

Whether or not these quasi-formal certifications will be accepted as useful by employers and will come to take on some kind of labor market premium may become clear over the next few years. If employers had better ways of assessing skills during the hiring process, these programs could significantly expand education options. With regard to MOOCs, an important task for the research agenda will be to hammer out what outcomes should be measured, beyond completion rates, to judge the success through closer investigations of where specifically they may add value to the education process. This will in turn require more nuanced study of students' reasons for accessing MOOCs, and, more broadly, the role of MOOCs within the broader education field.

6. Table 4

Study	Intervention	Data Source	Sample	Findings	Type
Alpert, Couch, and Harmon (2016)	Face-to-face, blended and purely online course content in a principles of microeconomics course	Administrative data of students' cumulative final exam scores from the course	College students of a principles of microeconomics course taught at a large public university in the Northeast.	(1) Those who completed the purely online course had learning outcomes that were significantly worse than those in the face-to-face section of the course (about four to five points or one-half of a letter grade) (2) No difference in outcomes those who completed the blended relative to the face-to-face course	Online
Banerjee and Duflo (2014)	"Deadline Effect" in the 1473: Challenges of Global Poverty MOOC - are students who register late less likely to do well or receive a certificate in the course?	Enrollment, performance and completion data from the 1473 MOOC	Students registering within 15 days of deadline for 1473: Challenges of Global Poverty MOOC	(1) Students who enrolled one day late were less likely to get a certificate (a reduction of 16.6 percentage points), and their grades were 10.7 percentage points lower. (2) Students whose behavior suggests that they are not organized are significantly less likely to succeed in a MOOC, and this is entirely driven by their failure to complete	MOOCs

				assignments on time, rather than by their performance conditional on completing them.	
Banerjee and Duflo (2016)	(1) Structured study time: A randomly chosen subset of students had the option to commit to a regular study time. (2) Self-efficacy messages: Students were randomly allocated to see either no message or one of three self-efficacy messages during the course entrance survey: (1) a generic message (2) a message related to females performing well in the course, (3) a message related to non-native English speakers performing well in the course. (3) Tutoring: All students that enrolled in the course were offered the opportunity to enter a lottery for tutoring services in groups of 20.	Data from the MOOC platform on course retention, interaction, completion and exam grades	19,694 online course participants	(1) There was no significant impact of regular study time, self-efficacy messages or of tutoring on eight outcomes of interest. (2) Those assigned to a tutoring group were more likely to have any interaction with staff (with tutor or on the forum); however, there was no impact on other measures of engagement.	MOOCs

Davis et al. (2017)	A personalized feedback system that facilitates social comparison of current students with previously successful learners.	Data from the MOOC online platforms on student characteristics, engagement, completion and performance.	Learners across four MOOCs provided by the Delft University of Technology on the edX platform	Across four randomized controlled trials in MOOCs, (1) the availability of social comparison cues significantly increases completion rates, (2) this type of feedback benefits highly educated learners, and (3) learners' cultural context plays a significant role in their course engagement and achievement.	MOOCs
Deming et al. (2016)	Resume audit of fictitious resumes varied by for-profit v. public, online v. brick-and-mortar, and more selective versus non-selective post-secondary institutions, based on degrees and programs in business and health	Secondary data collected from job vacancies, and primary data collected on "callbacks"	Employers posting job vacancies in business and health identified by a nationally recognized online job search website in five of the largest metropolitan labor markets in the U.S. Chicago, Los Angeles, Miami, New York City and San Francisco	(1) A business bachelor's degree from a for-profit online institution is 22 percent less likely to receive a callback than one from a nonselective public institution. (2) For health jobs, the for-profit credentials receive fewer callbacks unless the job requires an external quality indicator such as an occupational license	Online
Goodman, Melkers, and Pallais (2016)	The new Online Master of Science in Computer Science (OMSCS) offered by the Georgia Institute of Technology (Georgia Tech) and developed in partnership with Udacity and AT&T	Administrative data from (1) Georgia Tech's Computer Science Department on their applicant pool and (2) the National Student Clearinghouse on enrollment	Online and in person applicant pools for Georgia Tech's online and in person Computer Science Master's program	(1) Access to this online option substantially increases overall enrollment in formal education (by about 20 percentage points) and satisfies an unmet demand for mid-career training. (2) This opportunity is estimated to boost annual production of American computer science degrees by about 7 percent	Online

Joyce et al. (2015)	Amount of in class time on an introductory microeconomics course	Administrative data from Baruch college on student characteristics, previous academic performance, and course test scores and survey data on student attitudes.	725 college students at Baruch College in microeconomics course	Students in the traditional format scored 3.2 out of 100 points higher (0.21 SDs) on the midterm than those in the compressed format, but a statistically insignificant 1.6 points higher (0.11 SDs) on the final.	Online
Heppen et al. (2012)	Online algebra courses for credit recovery	Administrative records of credit recovery course grades, credit attainment, math courses taken in 10th grade and grades earned and student scores on the pre-ACT; student survey on student perceptions, and a self-administered post-course Algebra assessment	Two cohorts of students at Chicago Public Schools who failed Algebra I in 9th grade and enrolled in summer recovery program.	In both cohorts, students in the online course earned significantly lower grades and were less likely to recover credit than students in the face-to-face course.	Online - High School
Keefe (2003)	Two studies: (1) lecture and interaction online versus traditional face-to-face; (2) interaction versus regular lecture experience	Pre- and post-surveys on demographics and psychological measures and content based post-session exams	Six sections of 118 students in an Organizational Behavior course in Indiana University Southeast	(1) Students taking the course online rated the course and the professor less positively than students taking the course face-to-face; (2) Students taking the course online did 7.6 percent worse on exams that students taking the face-to-face course	Online

Kirabo, Jackson, and Makarin 2016	Off-the-shelf quality lessons and teacher support to promote their use	Administrative records for teachers and their students including teacher characteristics and student characteristics, student math achievement on the Virginia Standards of Learning assessment, teacher survey data on implementation	All middle school teachers in three school districts in Virginia	(1) Providing teachers with online access to the off-the-shelf lessons increased student math achievement by 0.06 SDs, (2) providing them with online access along with supports to promote their use increased students math achievement by 0.09 SDs.	Online
Kizilcec et al. (2014)	"Collectivist," "individualist" or "neutral" emails sent to MOOC participants to encourage forum participation	Data from the MOOC platform on forum participation	A subset of learners who enrolled in a MOOC on an undergraduate-level computer science topic at a major U.S. university	(1) The intervention has no significant effect on learners' decision to contribute to the forum, neither one week after the intervention, nor ten weeks. (2) The number of contributions made by learners receiving the individualist encouragement and the collectivist message are significantly lower than those receiving the neutral message, both one week and 10 weeks after the start of the course.	MOOCs

Kizilcec et al. (2017)	Mindset interventions addressing social identity threat using a "value relevance affirmation" exercise and a "social-belonging intervention"	Data from the online platforms on each MOOC on course persistence	Two samples: (1) 2286 students from a Computer Science MOOC offered at Stanford, (2) 1165 students in a 6 week Harvard MOOC	(1) The interventions had large effects consistent with predictions, eliminating the global achievement gap in both experiments; (2) In the first experiment, both interventions doubled persistence for learners in LDCs and didn't affect persistence for learners in MDCs; (3) In the second experiment, the social belonging intervention increases persistence for LDC learners without affecting persistence for MDC learners, and the affirmation experiment reduced persistence for MDC learners, but increased persistence for LDC learners	MOOCs
Lamb et al. (2015)	Self-assessment questions and aimed to improve forum participation for MOOC students : (1) a self-participation check, (2) discussion priming and (3) discussion preview emails	Data from the JusticeX platform on forum participation	MOOC students in JusticeX a HarvardX course	Self-assessment questions about forum participation encourage more students to engage in forums and increases the participation of already active students.	MOOCs
Martinez (2015A)	Emails informing students of their relative position in the course: (1) a "positive" one telling how many students recipients did better than, and (2) a "negative" one stating how other students outperformed the recipient	Data from the MOOC platform on quiz performance	Students registered for a Coursera MOOC, Foundations of Business Strategy at UVA	Emails lead to improved performance on subsequent quizzes (2 percentage points for "positive" emails and 3 percentage points for "negative" emails)	MOOCs

Martinez (2015B)	E-mails on the negative correlation between procrastination and achievement	Data from the MOOC platform on completion rates	24,122 students from the third Foundations of Business Strategy (FSB) MOOC at University of Virginia and 5,675 from the fourth FSB MOOC	(1) Students assigned to the treatment group were 16.85 percent more likely to complete the course. (2) Another randomized control trial demonstrated that the effect on the completion rate cannot be attributed to the Hawthorne effect.	MOOCs
Patterson (2015)	(1) A commitment device where students pre-commit to time limits on distracting Internet activities; (2) a reminder tool by time spent on districting websites; (3) a focusing tool that allows students to block distracting sites whole on the course website	Data from the MOOC platform on student effort and performance, including student characteristics collected from a pre-study survey	657 MOOC participants in a Stanford OpenX course	(1) Commitment device: 24 percent more time than control working on course and receive course grades 0.29 SDs higher; 40 percent more likely to complete the course; reminder and focusing treatments not significantly different from control	MOOCs
Poirier and Feldman (2004)	Traditional face-to-face versus online course	Primary data on student performance on a proctored exam.	Twenty-three students from a large state university who indicate that either a face-to-face or an online course was acceptable	Students in the online course performed better on exams and equally well on paper assignments compared to students in the traditional course. Results indicate that students who are amenable to taking either an online course of a traditional course performed as well in an online course as students enrolled in a large traditional course.	Online

Yeomans and Reich (2017)	Open-ended planning prompts asking students to describe any specific plans they made to engage course content and complete assignments on time.	Data from the MOOC platform on student enrollment, verification and grades	Students in 3 HarvardX MOOCs	Planning prompts increased course completion by 29 percent compared to the control condition. This effect size is similar to the difference between students who enrolled in and completed one MOOC before, and students who never enrolled in a MOOC	MOOCs
Zhang (2005)	The interactive e-classroom component of the LBA system versus traditional face-to-face classrooms	Student performance on content related post-test and student satisfaction survey	155 undergraduate students from a large public university in the United States	Students in the fully interactive multi-media based e-learning environment achieved better performance and higher levels of satisfaction than those in a traditional classroom and those in a less interactive e-learning environment.	Online
Zhang et al. (2006)	interactive video, non-interactive video and without video learning environments	Primary data collection including: a student pre-survey on student characteristics, a post-test and student questionnaire at the end of each session	138 undergraduate students from a large university in Southwest United States	(1) Students in the e-learning environment that provided interactive video achieved significantly better learning performance and a higher level of learner satisfaction than those in other settings. (2) However, students who used the e-learning environment that provided non-interactive video did not improve either. The findings suggest that it may be important to integrate interactive instructional video into e-learning systems.	Online

7. Conclusion

Technology has transformed large segments of society in ways that were once considered unimaginable. Education is no exception. Around the world, there is tremendous interest in leveraging technology to transform how students learn. In the coming years, new uses of ed-tech will continue to flood the market, providing students, parents, and educators with a seemingly limitless array of options. And experimental literatures are beginning to emerge in new domains, including in-class technology like iClickers[207] and adult education offered through text messages and other new platforms.[208]

Amidst the buzz and sizeable investment in ed-tech, we aim to step back and take stock of what we currently know from the experimental evidence in this nascent field. This review hopes to advance the knowledge base by identifying and discussing the most promising uses of ed-tech to date and highlighting areas that merit further exploration. We categorize the existing literature into four categories: 1) access to technology, 2) computer-assisted learning, 3) behavioral interventions, and 4) online courses.

We found that simply providing students with access to technology yields largely mixed results. At the K-12 level, much of the experimental evidence suggests that giving a child a computer may have limited impacts on learning outcomes, but generally improves computer proficiency and other cognitive outcomes. One bright spot that warrants further study is the provision of technology to students at the post-secondary level, an area with some positive RCT evidence.

From our review, computer-assisted learning and behavioral interventions emerge as two areas that show considerable promise. Especially when equipped with a feature of

[207] Lantz et al., 2013
[208] Aker et al., 2010; Ksoll et al., 2014.

personalization, computer-assisted learning can be quite effective in helping students learn, particularly with math. Two interventions in the United States stand out as being particularly promising—a fairly low-intensity online program that provides students with immediate feedback on math homework was found to have an effect size of 0.18 standard deviations, and a more intensive software-based math curriculum intervention improved seventh and eighth grade math scores by a remarkable 0.63 and 0.56 standard deviations. These results mirror those from promising interventions examined in the developing country literature, such as an adaptive learning software in India found to have large, positive impacts on Math and Hindi. In light of the promising evidence, more research is needed to understand the mechanisms behind computer-assisted learning, specifically how software interacts with teachers and current curriculum.

Like with computer-assisted learning, evaluations of behavioral interventions generally find positive effects across all stages of the education life cycle, although they are generally smaller than those found with the most effective computer-assisted learning models. At the same time, technology-enabled behavioral interventions, such as large-scale text message campaigns, are often extremely cheap to carry out and hold great promise as a cost-effective approach in education. Moving forward, researchers should prioritize understanding when technology-based behavioral nudges are most impactful. With the emergence of new approaches such as machine learning, additional research can help us understand how innovative technologies may further enhance behavioral interventions.

Though online learning courses have exploded in popularity over the last decade, there continues to be limited rigorous research to help us understand their effectiveness. From our review, we have found that, relative to courses with some degree of face-to-face teaching,

students taking online-only courses may experience negative learning outcomes. On the other hand, the effects of blended learning are generally on-par with those of fully in-person courses. This suggests that the appropriate combination of online and in-person learning may be cost-effective. As the online learning field is constantly evolving, new research is needed to understand how new models—such as MicroMasters programs and nanocredentials—may impact or democratize learning.

The ed-tech field is rapidly changing, and innovative tools and programs are frequently considered out-of-date after only several years. When faced with purchasing decisions, education administrators often demand research that is timely, relevant, and actionable. The direction of research and form of the research may need to change to integrate more seamlessly into decision-making. New tools have emerged to address some of these challenges, including Mathematica's Ed-Tech Rapid-Cycle Evaluation Coach and the EduStar RCT platform. While rapid-cycle product testing is of course valuable, more research is needed to evaluate how underlying mechanisms—rather than a specific product—can advance learning. In the end, it should not be about the most popular product or even necessarily the technology itself, but about the best way to help students of all ages and levels learn.

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