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Intelligent tutoring systems work as a math gap reducer in 6th grade after-school program

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ABSTRACT

Achievement gaps have been long-lasting problems in mathematics education. Racial/ethnic gaps, gender gaps, and differences between school socioeconomic status are three well-known contributors to gaps in achievement. This study explored the effect of an intelligent tutoring system, the Assessment and LEarning in Knowledge Spaces (ALEKS) system, on reducing such gaps in an after-school program. The study was conducted with a sample of 6th grade student volunteers who were randomly assigned to one of two after-school conditions (ALEKS versus comparable teacher-led mathematics teaching). In the teacher-led condition, White males and females and African American males and females coming from schools of two levels of socioeconomic status performed differently on the math state test. In contrast, in the ALEKS condition, students with different individual differences performed similarly on the state test. These findings provide encouragement for the use of computer technology assistance to aid in the education of disadvantaged students in math.

1. Introduction

1.1. Common math achievement gaps

Mathematics achievement is an important predictor of success. For example, performance on math tests at age seven substantially predicts the socioeconomic status of a person by age 42 (Ritchie & Bates, 2013). However, achievement gaps have consistently emerged between student groups. The most common gaps include racial/ethnic gaps, gender gaps, and differences between school socioeconomic status (SES). White students frequently perform better than African American students (Braun, Chapman, & Vezzu, 2010), males perform slightly better than females (Steinmayr, Wirthwein, & Schöne, 2014), and schools with high SES perform better than schools with low SES (Dronkers & Robert, 2008).

Results from national assessments (e.g., National Assessment of Educational Progress, NAEP) spanning decades revealed a significant racial/ethnic gap between White and African Americans during the 1970s, with that gap shrinking to one third of the size around the early 1990s (Berends, Lucas, Sullivan, & Briggs, 2005; Jencks & Phillips, 1998). However, there has been some setback since then (Lee, 2004). During 2000s, the gap was still sizable and robust (Braun et al., 2010; Clotfelter, Ladd, & Vigdor, 2009; Tesoro, Thompson, & Morris, 2014). Several reasons have been proposed about why there was a performance gap: disparities in educational quality from economic resources of schools combined with teachers' different expectations and practices; parenting environment and parents' involvement in children's schooling; and students' language proficiency, behavior, and motivation (Kurtz-Costes, Swinton, & Skinner, 2014).

While gender disparity was considered to be large in the past, current evidence does not support this view. Maccoby and Jacklin (1974) reviewed a wide variety of domains and psychological attributes (e.g., memory, motivations) and concluded that there were a number of gender differences. However, more recent meta-analyses of the literature have emphasized gender similarities (Hyde, 2005). In particular, the effect sizes were small or close to zero for male–female math-performance differences in the meta-analyses of studies published between the 1960s and 1980s (Friedman, 1989; Hyde, Fennema, & Lamon, 1990) and between the 1990s and 2000s (Lindberg, Hyde, Petersen, & Linn, 2010). Moreover, a summary of 46 meta-analyses published between 1985 and 2004 reported that 78% of effect sizes were small, suggesting that males and females are alike on most, but not all characteristics (Hyde, 2005; Hyde & Linn, 2006). Gender differences have often been observed in comparisons between nations or races/ethnics (i.e., the studies investigate both gender and racial/ethnic/national factors), indicating gender differences at sub-levels. One meta-analysis reported such gender gaps across nations (Else-Quest, Hyde, & Linn, 2010).

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The third common gap addresses school socioeconomic status. A large number of factors contribute to school differences, with socioeconomic background explaining a major percentage of the variance (Organization for Economic Co-operation and Development (OECD), 2004; Suárez-Álvarez, Fernández-Alonso, & Muñiz, 2014). The average socioeconomic status of students at a school was positively associated with student achievement (Battistich, Solomon, Kim, Watson, & Schaps, 1995; Dronkers & Robert, 2008; McLoyd, 1998; Palardy, 2008). Some typical indicators of school-level socioeconomic status (SES) are the percentage of students eligible for free or reduced-price lunch in the U.S. (Battistich et al., 1995; Clayton, 2011) and reduced or no tuition in other countries (Hein, Tan, Aljughaiman, & Grigorenko, 2015). Another popular indicator is the school location as being urban or rural (Miller, Votruba-Drzal, & Setodji, 2013), with lower achievement in rural schools compared with their urban counterparts (Dronkers & Robert, 2008).

1.2. Possible solution from intelligent tutoring system

Intelligent tutoring systems (ITS) are computer systems that aim to adapt to the needs of users and provide customized instructions and feedback to individuals without intervention from a human (Self, 1999; Woolf, 2009). With ITS, students receive customized learning materials and formative feedback on correct performance and errors. ITS have been commercialized and used in K–12 and higher education (Kulik & Fletcher, 2015; Ritter, Anderson, Koedinger, & Corbett, 2007; VanLehn, 2011; Woolf, 2009).

ITS applications have shown higher learning gains than teacher-led, large-group instruction (Ma, Adesope, Nesbit, & Liu, 2014; Steenbergen-Hu & Cooper, 2013; VanLehn, 2011). ITS have been demonstrated to vary in effectiveness between $\sigma = 0.40$ and $\sigma = 0.80$ (Fletcher, 2003; Graesser, Conley, & Olney, 2012; Ma et al., 2014; Steenbergen-Hu & Cooper, 2013, 2014; VanLehn, 2011) with an average $\sigma = 0.60$. These numbers are comparable to human tutoring which varies from between $\sigma = 0.20$ and $\sigma = 1.00$ (Cohen, Kulik, & Kulik, 1982; Graesser, D'Mello, & Cade, 2011).

The recent efficacy studies consider properties of students such as gender, race/ethnicity, and free-lunch status (Feng, Heffernan, & Koedinger, 2010) and report that these factors do help to predict student knowledge (Feng & Beck, 2009). For example, Wolff, Zdrahal, Herrmannova, and Knoth (2014) reported that demographic data predict fine-grained performance in short learning sessions.

One interesting finding is that ITS can equalize mathematics achievement across student demographic groups. In particular, researchers have discovered a racial/ethnic similarity between the math performance of African American students and White students who learn from ALEKS (Cheney et al., 2011; Hu, Xu, Hall, Walker, & Okwumabua, 2013). White students performed significantly better than African American students in teacher-lecture classes whereas the performance differences were eliminated in ITS classes in which students were completely taught by the ALEKS system (Hu et al., 2013). Similar results have been found for Hispanic students (Roschelle et al., 2010). There is evidence that this achievement similarity between racial/ethnic groups using an ITS has been found in a number of studies with K–12 students (Li & Ma, 2010). All these studies have suggested the efficacy of ITS in helping students from different races/ethnicities. Whites, African Americans, and Hispanics appear to benefit nearly equally from technology.

ITS also demonstrated reductions in performance differences between genders. An evaluation conducted by Arroyo, Woolf, Royer, Tai, and English (2010) reported that ITS are highly effective for both genders. Roschelle et al. (2010) reported that male students have higher pre-intervention performance than females, but male and female students showed similar learning gains after an ITS intervention. The Li and Ma (2010) meta-analysis also reported an absence of gender gap in computerized education for all three types of school composition: predominantly female, predominantly male, and gender balanced. The lack of a gender gap indicates that educational systems are effective for both boys and girls.

1.3. ALEKS, a mathematics based ITS

ALEKS is a web-based learning system with artificial intelligence components that are based in *Knowledge Space Theory* (Falmagne, Koppen, Villano, Doignon, & Johannesen, 1990). The theory divides a subject matter, in our case 6th grade math, into approximately 370 basic concepts that combinatorically into a knowledge space structure with millions of possible knowledge states. Instead of giving scores to describe a student's overall mastery of the subject, the theory allows for a precise description of what the student knows, does not know, and is ready to learn next. The student is situated somewhere in the space at each point in learning and transitions to a new state at each learning increment. Questions (and problem types) are associated with particular knowledge states. ALEKS administers a 25 to 35 question test to determine a student's initial knowledge state. If the student answers a question (problem type) correctly, the mastery probability of the knowledge state containing that problem type increases. The process iterates until there is one knowledge state with a much higher probability than the others to be learned and the associated question type is the one whose solution the student is ready to learn.

ALEKS provides, in the form of a pie chart, a summary of what the student knows and is ready to learn. Fig. 1 depicts the topic selection interface in ALEKS. This interface shows students how much of each knowledge category has been mastered and provides students with a list of problems that they are ready to work on based on knowledge space theory. Students can choose any topic in the list. Once the system determines that the problem type had been mastered, it is added to the student's knowledge state, and another problem type that is ready to be learned can be chosen. Subsequent assessments update the student's knowledge state.

ALEKS was selected for the current study because it was available and performs as the same level as other major ITS systems in mathematics (Sabo, Atkinson, Barrus, Joseph, & Perez, 2013), such as *Cognitive Tutor* (Ritter et al., 2007). Moreover, Sullins et al. (2013) reported a strong positive relationship between the assessment performance in ALEKS and the Tennessee mathematics state test scores for students of 6th, 7th, 8th, and 9th grades. The students tutored by ALEKS or taught by expert teachers in one after-school program showed the same level of performance in a mathematics state test, and outperformed other students who did not participate in the after-school program (Hu et al., 2011). The students in ALEKS classrooms required significantly less assistance from teachers to complete their daily work than students in teacher classrooms (Craig et al., 2013). Furthermore, students working with ALEKS reported more positive attitudes toward both mathematics learning and math learning with computers (Huang, Xie, Graesser, Hu, & Craig, 2014).

1.4. Practicability of ITS for low-income students

In order to investigate the effect of ITS on students with low socioeconomic status, studies need to consider students' daily access to computer and internet because the regular access is crucial for the further practical application of research findings. Though low-income students had little access to computers and internet at the end of the 20th century (National Telecommunications and Information Administration, 1999), recent reports have confirmed that almost all public schools have internet-linked computers (OECD, 2013), even in schools with 75% or more students eligible for free or reduced-price lunch. Furthermore, 99% of students will be able to access next-generation broadband and high-speed wireless in schools by the year 2018 according to ConnectED initiative (White House, 2013). Though access to a computer at home is less common than access at school, most households with