# Does CAI Improve Early Math Skills?

Haya Shamir, Kathryn Feehan and Erik Yoder
*Waterford Institute, 1590 East 9400 South, Sandy, UT, 84093, U.S.A.*

Keywords: Computer-Assisted Instruction (CAI), Math, Early Childhood.

Abstract: The Waterford Early Math and Science Program is a computer-assisted instruction program that ensures individualized learning for kindergarten through first grade students. The Waterford curriculum was assigned to students in a school district in Indiana for the 2015-2016 school year. The Mobile Classroom: Math assessment was administered to students at the beginning, middle, and end of the school year to assess math skills across multiple strands. Analysis revealed statistically significant higher end of year scores on most assessment strands made by kindergarten and first grade students that used the Waterford Early Math and Science Program, indicating that Waterford curriculum improves early math skills.

## 1 INTRODUCTION

The achievement gap is the difference in academic success between students of ethnic minority and/or students of low socioeconomic status and their White student counterparts and/or students of higher socioeconomic status (Maulbeck, 2015). This academic achievement gap separates the lower- and higher-achieving students from one another, and the gap widens as students continue into later grades (Harris et al., 2016). If not addressed, the gap can be widened in schools when students of all demographics are not taught according to their needs: According to Heckman's research, early interventions followed by high quality education are most effective in preventing the achievement gap between students of low socioeconomic status and students of high socioeconomic status (Education, 2011). Clearly, students of lower socioeconomic status need to have access to effective curriculum to prepare them for academic success despite their backgrounds.

Students need basic operational knowledge and number competence in order to succeed in mathematics when entering elementary school (Jordan et al., 2009; Welsh et al., 2010). Most children acquire numeracy knowledge before they enter kindergarten, and this basic numerical knowledge or lack thereof impacts mathematical success in school through high school (Claessens and Engel, 2013; National Mathematics Advisory Panel, 2008). Moreover, early numeracy skills assessed in kindergarten as measured by test scores and teacher reports predicted mathematics performance in first grade (Aunio and Niemivirta, 2010), in third grade (Jordan et al., 2009), and through eighth grade (Claessens and Engel, 2013). Early math achievement is predictive of later math, reading, and science achievement, so foundational knowledge of math is essential for success in school (Claessens and Engel, 2013).

Computer-assisted instruction (CAI) is the presentation of different forms of educational media material in an interactive, instructional way. While teachers conduct large group instruction meant for many students to learn a subject, CAI allows individual students to take control of their learning which increases students' flexibility, interactivity, and engagement (Jethro et al., 2012). According to research of CAI in the classroom setting, early childhood instruction using CAI can improve mathematical performance (Aunio and Niemivirta, 2010) in comparison to a typical public classroom setting. Moreno (2006) suggests a cognitive theory of learning with media (CTLM), wherein students learn better when given opportunities to reflect on information they have learned, where multimedia presentations of material are more conducive to retention, and where words and graphics expand working-memory capacity. CAI presents material with animation and immediate feedback, individualizing the learning process.

Differences in academic achievement and cognitive abilities in the early years lead to a need for



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technology applications that scaffold, are individualized, and adjust to a child's ability level (Wang et al., 2010). This need for individualized educational technology programs includes programs targeting students of all demographics. CAI technology can significantly improve mathematics achievement in at-risk pre-kindergarten students (Clements et al., 2011), at-risk elementary school students (Clements and Sarama, 2008), and middle and high school students (Barrow et al., 2009) in comparison to traditional classrooms. However, while computer-assisted instruction has been well documented to improve the early literacy and math academic achievement, studies have also proven that computer-assisted instruction presents challenges to students from low-income families (Kitchen and Berk, 2016; Slavin and Lake, 2008). Results are not all in favor of CAI incorporated with in-school instruction, so further research is needed to examine the impact of CAI technology on literacy and math scores of early elementary students (Cheung and Slavin, 2011; Macaruso and Walker, 2008).

The purpose of the present study was to evaluate the effectiveness of the Waterford Early Math and Science Program in improving early math skills of kindergarten through second grade students. The computer-assisted instruction program, we predict, will improve math scores when incorporated into early elementary school programs.

# 2 METHODS

## 2.1 Participants

This study consisted of 602 students enrolled in a public school district in Indiana during the 2015-2016 school year. The majority of students in the study are White, and approximately half of the students qualify for free lunch.

The experimental group for kindergarten consisted of 114 students, and the control group consisted of 58 students. For first grade, the experimental group consisted of 68 students, and the control group consisted of 255 students.

## 2.2 Materials

### 2.2.1 The Waterford Early Math and Science Program (EMS)

The program offers a comprehensive, computer-adaptive math and science curriculum for pre-kindergarten through second grade students. The software presents a wide range of multimedia-based activities in an adaptive sequence tailored to each student's initial placement and his or her individual rate of growth throughout the complete math and science curriculum.

### 2.2.2 Mobile Classroom: Math (mCLASS: Math)

The assessment mCLASS: Math was designed to assess early mathematics skills and identify at-risk students in need of remedial early mathematics assistance. The assessment measures fundamental skills required by the Common Core State Standards in mathematics for kindergarten through third grade.

## 2.3 Procedure

Students were expected to use EMS for thirty minutes per day, five days per week, throughout the 2015-2016 school year. Usage was tracked within the program and monitored weekly by Waterford personnel, and total minutes of usage of EMS for the school year per group was calculated.

The mCLASS: Math assessment was administered three times throughout the school year, at the beginning, middle, and end of the year.

The experimental group for kindergarten consisted of students that used EMS for more than 1,000 minutes throughout the 2015-2016 school year, and the control group consisted of students that used EMS for less than 400 minutes throughout the 2015-2016 school year. For first grade, the experimental group consisted of students that used EMS for more than 1,000 minutes throughout the 2015-2016 school year, and the control group consisted of students that did not use EMS.

# 3 FINDINGS

## 3.1 Kindergarten

### 3.1.1 Group Differences using ANCOVAs

ANCOVAs examining group differences in mCLASS: Math end of year scores while covarying for beginning of year scores were conducted (see Figures 1-2).

Analysis of Number Identification end of year scores, while covarying for beginning of year scores, revealed a significant difference between groups, $F(1, 168) = 7.34$, $p < .01$, due to higher end of year scores made by students who used Waterford ($M = 32.38$)

than by control students ($M$ = 28.25). Effect size ($d$ = 0.42).

Analysis of Quantity Discrimination end of year scores, while covarying for beginning of year scores, revealed a significant difference between groups, $F(1, 168) = 4.30$, $p < .05$, due to higher end of year scores made by students who used Waterford ($M$ = 30.80) than by control students ($M$ = 28.12). Effect size ($d$ = 0.32).

Analysis of Counting end of year scores, while covarying for beginning of year scores, did not reveal a significant difference between groups, $F(1, 168) = 3.43$, $p = .066$, however Waterford students had higher end of year scores ($M$ = 88.64) than control students ($M$ = 84.33).

Analysis of Missing Number end of year scores, while covarying for beginning of year scores, did not reveal a significant difference between groups, $F(1, 168) = 0.04$, $p = .839$, however Waterford students had higher end of year scores ($M$ = 15.70) than control students ($M$ = 15.53).

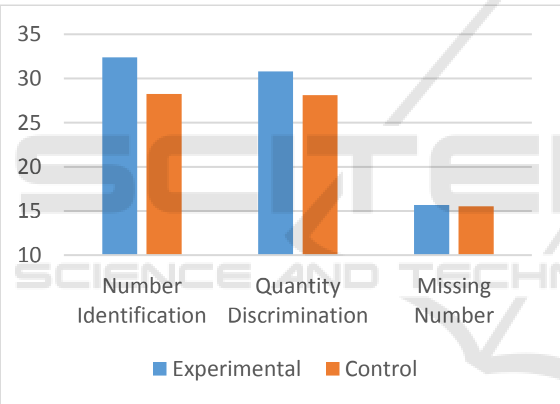


Figure 1: Kindergarten mCLASS: Math end of year scores by substrand.

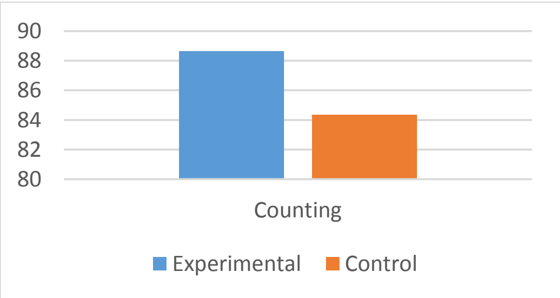


Figure 2: Kindergarten mCLASS: Math Counting end of year scores.

### 3.1.2 Group Differences by Demographics using ANCOVAs

Further analysis was conducted to examine the effects of gender, lunch program, and special education status on Number Identification end of year scores (see Figure 3).

There was no significant interaction between the effects of gender and Waterford curriculum on Number Identification end of year scores, covarying for beginning of year scores, $F(1, 166) = 2.90$, $p = .091$. Simple effects analysis showed that for females, students in the experimental group significantly outperformed students in the control group. Male students' scores in the experimental group were slightly higher than in the control group, but the difference was not significant.

There was no significant interaction between the effects of lunch program and Waterford curriculum on Number Identification end of year scores, covarying for beginning of year scores, $F(2, 164) = 1.10$, $p = .334$. Simple effects analysis showed that for reduced lunch, students in the experimental group significantly outperformed students in the control group. Free lunch and regular lunch students' scores in the experimental group were slightly higher than in the control group, but the difference was not significant.

There was no significant interaction between the effects of special education status and Waterford curriculum on Number Identification end of year scores, covarying for beginning of year scores, $F(1, 166) = 0.53$, $p = .468$. Simple effects analysis showed that for students with no special education status, the experimental group significantly outperformed the control group. For students with active special education status, scores in the experimental group were slightly higher than in the control group, but the difference was not significant.

Further analysis was conducted to examine the effects of gender, lunch program, and special education status on Quantity Discrimination end of year scores (see Figure 4).

There was no significant interaction between the effects of gender and Waterford curriculum on Quantity Discrimination end of year scores, covarying for beginning of year scores, $F(1, 166) = 0.12$, $p = .729$. Simple effects analysis showed that for males and females, students' scores in the experimental group were slightly higher than in the control group, but the difference was not significant.

There was no significant interaction between the effects of lunch program and Waterford curriculum on Quantity Discrimination end of year scores

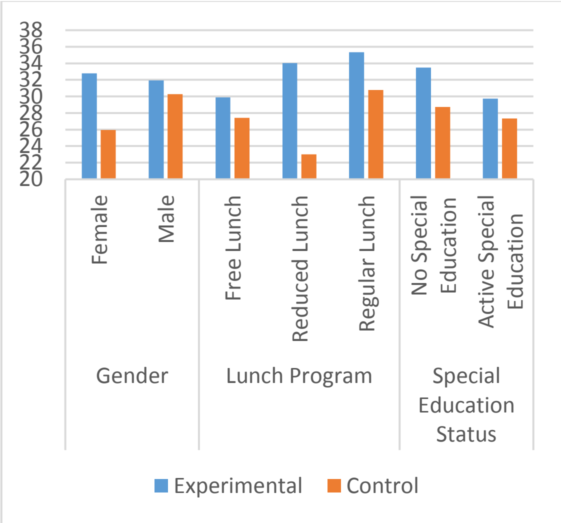


Figure 3: Number identification end of year scores by demographics.

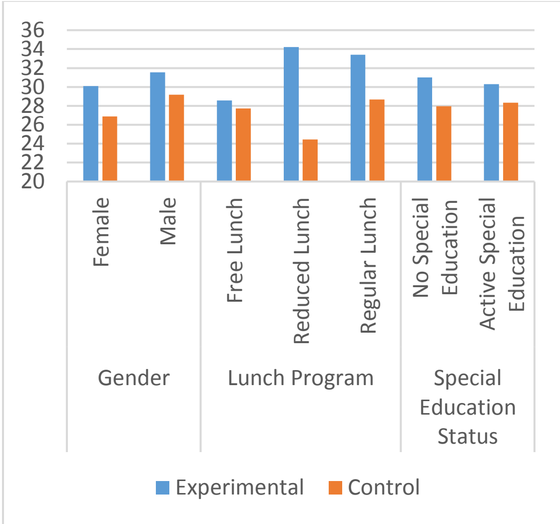


Figure 4: Quantity discrimination end of year scores by demographics.

covarying for beginning of year scores, $F(2, 164) = 2.41$, $p = .093$. Simple effects analysis showed that for reduced lunch and regular lunch, students in the experimental group significantly outperformed students in the control group. Free lunch students' scores in the experimental group were slightly higher than in the control group, but the difference was not significant.

There was no significant interaction between the effects of special education status and Waterford curriculum on Quantity Discrimination end of year scores, covarying for beginning of year scores, $F(1, 166) = 0.17$, $p = .677$. Simple effects analysis showed that for students with no special education status and active special education status, scores in the experimental group were slightly higher than in the control group, but the difference was not significant.

## 3.2 First Grade

### 3.2.1 Group Differences using ANCOVAs

ANCOVAs examining group differences in mCLASS: Math end of year scores while covarying for beginning of year scores were conducted (see Figures 5-6).

Analysis of Number Identification end of year scores, while covarying for beginning of year scores, did not reveal a significant difference between groups, $F(1, 320) = 0.06$, $p = .813$, however Waterford students ($M = 52.40$) scored slightly higher than control students ($M = 52.12$).

Analysis of Number Facts end of year scores, while covarying for beginning of year scores, revealed a significant difference between groups, $F(1, 320) = 9.06$, $p < .01$, due to higher end of year scores made by students who used Waterford ($M = 14.02$) than by control students ($M = 12.69$). Effect size ($d = 0.34$).

Analysis of Quantity Discrimination end of year scores, while covarying for beginning of year scores, revealed a significant difference between groups, $F(1, 320) = 5.88$, $p < .05$, due to higher end of year scores made by students who used Waterford ($M = 42.17$) than by control students ($M = 39.78$). Effect size ($d = 0.27$).

Analysis of Counting end of year scores, while covarying for beginning of year scores, did not reveal a significant difference between groups, $F(1, 320) = 0.66$, $p = .416$, however Waterford students ($M = 107.08$) scored slightly higher than control students ($M = 106.03$).

Analysis of Missing Number end of year scores, while covarying for beginning of year scores, revealed a significant difference between groups, $F(1, 320) = 15.07$, $p < .01$, due to higher end of year scores made by students who used Waterford ($M = 25.90$) than by control students ($M = 23.12$). Effect size ($d = 0.43$).

Analysis of Next Number end of year scores, while covarying for beginning of year scores, revealed a significant difference between groups, $F(1, 320) = 6.18$, $p < .05$, due to higher end of year scores made by students who used Waterford ($M = 23.77$) than by control students ($M = 22.09$). Effect size ($d = 0.28$).

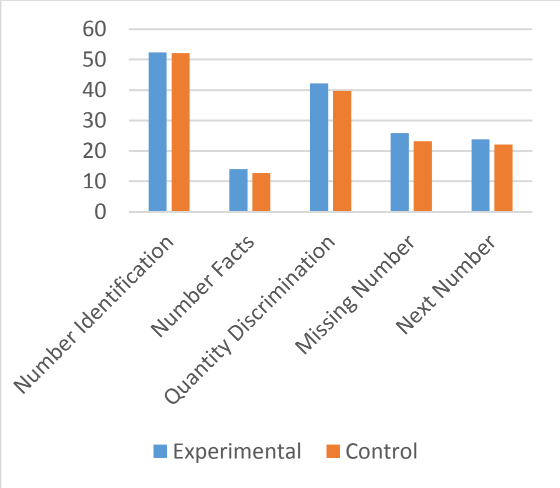


Figure 5: First grade mCLASS: Math end of year scores by substrand.

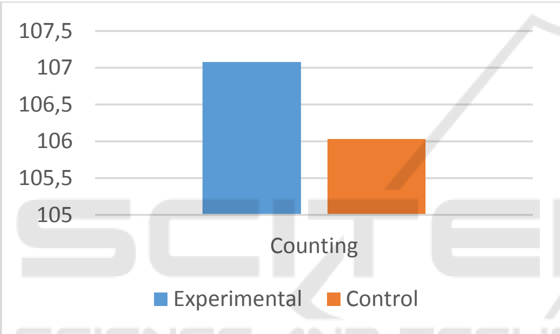


Figure 6: First grade mCLASS: Math counting end of year scores.

### 3.2.2 Group Differences by Demographics using ANCOVAs

Further analysis was conducted to examine the effects of gender, lunch program, and special education status on Number Facts end of year scores. (see Figure 7).

There was no significant interaction between the effects of gender and Waterford curriculum on Number Facts end of year scores, covarying for beginning of year scores, *F*(1, 317) = 0.05, *p* = .818. Simple effects analysis showed that for males, students in the experimental group significantly outperformed students in the control group. Female students' scores in the experimental group were slightly higher than in the control group, but the difference was not significant.

There was no significant interaction between the effects of lunch program and Waterford curriculum on Number Facts end of year scores, covarying for beginning of year scores, *F*(2, 310) = 2.86, *p* = .059. Simple effects analysis showed that for free lunch and regular lunch, students in the experimental group significantly outperformed students in the control group.

There was no significant interaction between the effects of special education status and Waterford curriculum on Number Facts end of year scores, covarying for beginning of year scores, *F*(1, 317) = .00, *p* = .982. Simple effects analysis showed that for students with no special education status, the experimental group significantly outperformed the control group. For students with active special education status, scores in the experimental group were slightly higher than in the control group, but the difference was not significant.

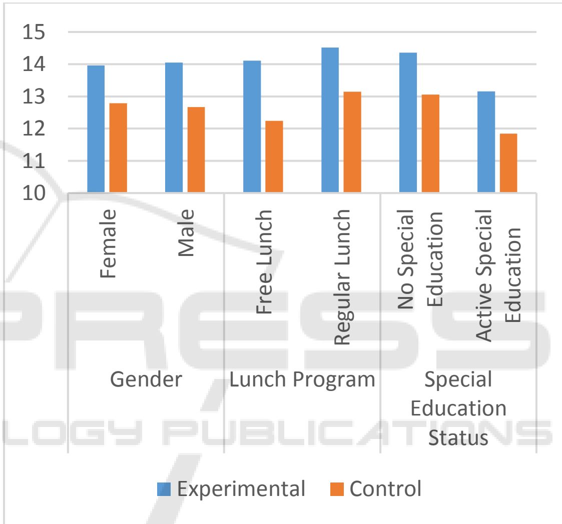


Figure 7: First grade number facts end of year scores by demographics.

Further analysis was conducted to examine the effects of gender, LEP status, lunch program, and special education status on end of year Quantity Discrimination scores (see Figure 8).

There was no significant interaction between the effects of gender and Waterford curriculum on Quantity Discrimination end of year scores, covarying for beginning of year scores, *F*(1, 317) = 0.01, *p* = .918. Simple effects analysis showed that for males and females, students' scores in the experimental group were slightly higher than in the control group, but the difference was not significant.

There was no significant interaction between the effects of LEP status and Waterford curriculum on Quantity Discrimination end of year scores, covarying for beginning of year scores, *F*(1, 317) = 0.56, *p* = .457. Simple effects analysis showed that

Non-LEP students' scores in the experimental group were slightly higher than in the control group, approaching significance. LEP students' scores in the experimental group were slightly higher than in the control group, but the difference was not significant.

There was no significant interaction between the effects of lunch program and Waterford curriculum on Quantity Discrimination end of year scores, covarying for beginning of year scores, $F(2, 310) = 0.37$, $p = .694$. Simple effects analysis showed that for free lunch, students in the experimental group significantly outperformed students in the control group. Reduced lunch and regular lunch students' scores in the experimental group were slightly higher than in the control group, but the difference was not significant.

There was no significant interaction between the effects of special education status and Waterford curriculum on Quantity Discrimination end of year scores, covarying for beginning of year scores, $F(1, 317) = 2.01$, $p = .158$. Simple effects analysis showed that for students with no special education status, the experimental group significantly outperformed the control group. For students with active special education status, scores in the experimental group were slightly higher than in the control group, but the difference was not significant.

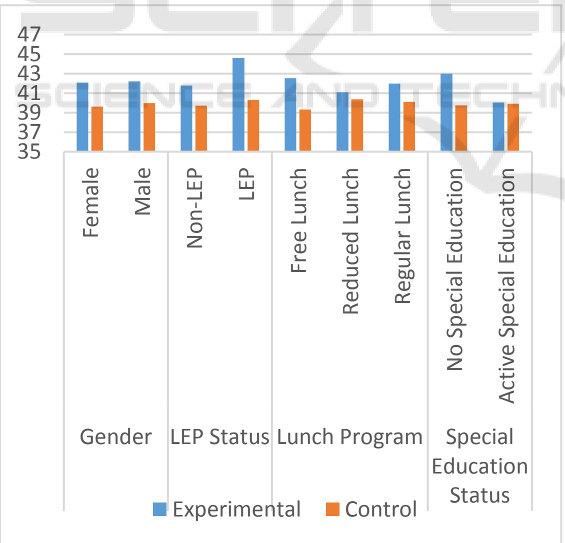


Figure 8: First grade quantity discrimination end of year scores by demographics.

Further analysis was conducted to examine the effects of gender, LEP status, lunch program, and special education status on end of year Missing Number scores (see Figure 9).

There was no significant interaction between the effects of gender and Waterford curriculum on Missing Number end of year scores, covarying for beginning of year scores, $F(1, 317) = 0.17$, $p = .682$. Simple effects analysis showed that for males and females, students in the experimental group significantly outperformed students in the control group.

There was no significant interaction between the effects of LEP status and Waterford curriculum on Missing Number end of year scores, covarying for beginning of year scores, $F(1, 317) = 1.47$, $p = .227$. Simple effects analysis showed that Non-LEP students in the experimental group significantly outperformed students in the control group. LEP students' scores in the experimental group were slightly higher than in the control group, but the difference was not significant.

There was no significant interaction between the effects of lunch program and Waterford curriculum on Missing Number end of year scores, covarying for beginning of year scores, $F(2, 310) = 0.32$, $p = .730$. Simple effects analysis showed that for free lunch and regular lunch, students in the experimental group significantly outperformed students in the control group. Reduced lunch students' scores in the experimental group were higher than in the control group, approaching significance.

There was no significant interaction between the effects of special education status and Waterford curriculum on Missing Number end of year scores, covarying for beginning of year scores, $F(1, 317) = 0.32$, $p = .574$. Simple effects analysis showed that for students with no special education status, the experimental group significantly outperformed the control group. For students with active special education status, scores in the experimental group were slightly higher than in the control group, but the difference was not significant.

Further analysis was conducted to examine the effects of gender, LEP status, lunch program, and special education status on Next Number end of year scores (see Figure 10).

There was no significant interaction between the effects of gender and Waterford curriculum on Next Number end of year scores, covarying for beginning of year scores, $F(1, 317) = 0.07$, $p = .787$. Simple effects analysis showed that for males, students in the experimental group significantly outperformed students in the control group. Female students' scores in the experimental group were slightly higher than in the control group, but the difference was not significant.

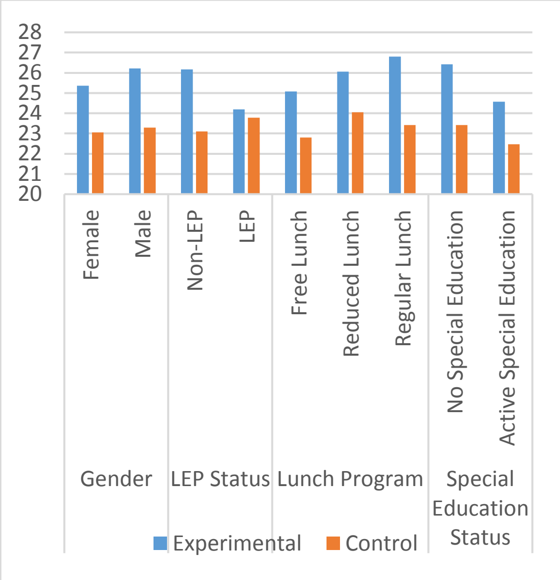


Figure 9: First grade missing number end of year scores by demographics.

There was no significant interaction between the effects of lunch program and Waterford curriculum on Next Number end of year scores, covarying for beginning of year scores, $F(2, 310) = 0.26$, $p = .775$. Simple effects analysis showed that for regular lunch, students in the experimental group significantly outperformed students in the control group. Free lunch and reduced lunch students' scores in the experimental group were slightly higher than in the control group, but the difference was not significant.

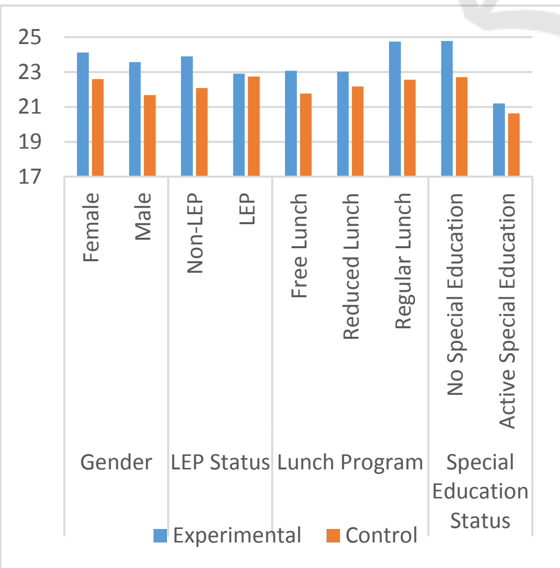


Figure 10: First grade quantity discrimination end of year scores by demographics.

There was no significant interaction between the effects of special education status and Waterford curriculum on Next Number end of year scores, covarying for beginning of year scores, $F(1, 317) = 1.03$, $p = .312$. Simple effects analysis showed that for students with no special education status, the experimental group significantly outperformed students in the control group. For students with active special education status, scores in the experimental group were slightly higher than in the control group, but the difference was not significant.

## 4 DISCUSSION

According to previous research of CAI programs in early childhood education, early mathematical performance can be improved by incorporating CAI technology into an existing school curriculum (Aunio and Niemivirta, 2010). Similar to previous studies, performance on various strands of math were higher for students who used the Waterford Early Math and Science Program, indicating the benefit of adding CAI to an existing curriculum. Almost universally, students in the experimental group outperformed students in the control group across demographics and across grades. These findings are supported by previous findings that CAI technology improves early math scores when added to an existing curriculum (Ecalle et al., 2013; Falth, Gustafson et al., 2013; López, 2010).

Students who had the most usage of the CAI software showed the highest achievement on the assessments, which suggests that if the software was implemented with the minimum usage expectations for all students, the positive effects on academic achievement would have been even higher. A limitation of this study is that the students were from a single school district, and the vast majority of students were Caucasian. Having a more ethnically diverse sample, as well as students from multiple school districts, would allow these results to be more generalizable. The addition of CAI in a classroom setting, overall, provides effective individual instruction for each student in early math.

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