Evidence for Dosage and Long-Term Effects of Computer-Assisted Instruction

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***Abstract*—While Computer-Assisted Instruction (CAI) has been shown to positively impact learning outcomes in the short-term, longitudinal research has demonstrated that gains diminish with time. It is important for research to demonstrate that this increasingly prominent technology is preparing young students for successful scholastic careers. The current longitudinal study explored the long-term impact of an adaptive CAI program on young students' literacy skills. Two cohorts of elementary school students used Waterford Early Learning (WEL) in kindergarten, first grade, or both kindergarten and first grade during the 2015-2016 and the 2016-2017 school years. The Developmental Reading Assessment (DRA) was administered to students at the end of the 2016-2017 and 2017-2018 school years when students were in first or second grade. Scores of students in both cohorts who used WEL only during kindergarten or first grade (for one year only) or in kindergarten and first grade (for two years) were compared to scores of students who received traditional, teacher-directed classroom instruction. Analysis indicated a salient and persistent effect of CAI: One to two years after students stopped using the program, students who used WEL for one or two years outperformed students who did not use WEL. Additionally, evidence was found for a dosage effect: While all students who used WEL had higher end of year scores than students who did not use WEL, the largest effects were found for students with high CAI usage. The findings of the current study extend prior research which had found that better results within a single school year could scale with increased use of CAI. Given the evidence found for both a lasting benefit and a dosage effect, the current study endorses the sustained use and early implementation of CAI.**

***Index Terms*—Computer-Assisted Instruction (CAI), literacy, early childhood**

I. Introduction

Due to the rapid emergence of digital technology in the last decades of the twentieth century, education has had to adapt to the new generation of digital natives [1]. The students of today are experiential learners, and current schooling practices are adapting to relate to this generation's interest in games-based learning [2]. Bridging the gap from home to school, researchers have encouraged the development of technology in schools that is relative to the amount of technology that children are exposed to in the home [3], [4]. However, research has led to conflicting findings on the success of technology on digital natives in school, and there is still a gap in research on the relationship between young children's learning and developmentally appropriate technology in early reading instruction [5], [6]. To adapt to the generation of digital natives, the United States has invested greatly in educational technology over the past two decades [7]. Recent efforts to improve reading instruction on a national scale, like the No Child Left Behind Act and its accompanying Early Reading First program, have moved public schools toward setting more specific goals for accountability and instructional methods for reading [8]; however, results have not proven to be unequivocally positive. Scores from the 2013 NAEP show that progress in early reading achievement continues to be very slow, even though progress has been made by lower-performing students in the early grades [9]. Making improvements to early reading instruction continues to present a significant problem for both educators and policymakers.

More recent innovations in technology and increases in federal funding for education have led to dramatic increases in the tools available for teachers and students [10]. Students are learning with tablets [11], digital storybooks [12], and smart whiteboards [13], and the curriculum they are learning can itself be the product of technology. The concept of computer-assisted instruction (CAI) is not a new idea, but it is one that is increasingly relevant. As technology has developed, CAI has moved from theory and initial pilot studies [14] to widespread implementation [15]. CAI presents students with different forms of interactive and instructional educational media. This presentation of dynamic material aids in retention and helps to expand students' working-memory capacity [16]. CAI allows for individualized learning; unlike traditional large group instruction, individual students will be presented appropriate content and provided meaningful feedback [17]. This approach allows students to take control of their learning and increases their flexibility, interactivity, and engagement with a lesson. Research has demonstrated that CAI benefits young students' math [18] and literacy skills [19]. When implemented with fidelity, CAI technology has been found to be effective for all populations, with specific benefits for young learners [20]. CAI technology can significantly improve academic achievement in at-risk

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pre-kindergarten students [21], [22] and middle and high school students [23] in comparison to traditional classrooms.

Early research into CAI found the approach to be an effective, if occasionally inefficient, means of increasing learning outcomes [24], [25]. In the age before the omnipresent personal computer, studies reliably demonstrated that CAI interventions increased reading and math achievement. However, the same body of literature pointed out technical issues with implementation and that comparable gains could be had with conventional interventions at lower costs [25], [26]. Efficiency has improved with time. Recent literature has indicated that CAI may now be a more effective tool than traditional interventions [27]. A study comparing reading outcomes for one-to-one tutoring and CAI found that schools that used CAI curriculum could provide more students with the extra assistance they required. The structural benefits of CAI can ensure each student spends more time in class successfully engaging with the material [28].

Longitudinal research has explored the longevity of CAI's impact on literacy skills [29], [30]. Globally, studies have offered support for the relative salience of CAI on basic linguistic skills, independent of the language being taught [31]. At-risk students using a CAI curriculum, observed through first and second grade, demonstrated marked improvement in literacy skills to the point of achieving parity with comparison students at the end of second grade [32]. Additionally, beneficial effects of CAI curriculum on literacy skills of first grade students have been observed months from the original intervention [33]. However, while strong or moderate effects were found immediately after CAI interventions, these effects diminished with time, fading to small in less than a year [30]. Notably, effects of CAI interventions were shorter lived for lower grades, yet previous literature has suggested that early intervention plays an important role in ensuring future academic success [34]. Further research is required to ensure that any CAI curriculum intended for early learners has a salient effect.

Longitudinal research into CAI has yet to reach a consensus on the potential for a dosage effect. For a broad range of literacy interventions, including more traditional approaches, increased levels of exposure to a given intervention can lead to increased benefits for students [35]. Students receiving a high dose of a literacy intervention will tend to show greater gains in literacy skills than students receiving a lower dosage in the same time-period [36]. Non-longitudinal research has demonstrated that students with high usage of a CAI curriculum can see greater benefits in literacy [37] and math [38] skills compared to students with lower usage of the same curriculum. Early research exploring this phenomenon specifically with CAI offered some support for a compounding benefit over multiple years; primary school students were followed over three consecutive years, by the end of which students receiving CAI instruction dramatically outperformed control students [39]. However, a recent meta-analysis into the comparative benefits of various approaches to vocabulary interventions, including CAI approaches, found no evidence of a dosage effect [40]. Further research is necessary to assess whether students benefit from increased exposure to CAI interventions over an extended timeframe.

The purpose of the current study was to explore the benefits of long-term use of a CAI program for elementary school students. It is predicted that the program will have lasting effects on students' literacy skills after they cease to use it.

II. Methods

A. Participants

This study consisted of two distinct cohorts of elementary school students enrolled in a public school district in South Carolina. Cohort 1 (n = 3,325) was assessed at the end of the 2016-2017 school year. Cohort 2 (n = 3,254) was assessed at the end of the 2017-2018 school year.

Cohort 1 first grade groups consisted of students with usage in kindergarten and first grade, usage in kindergarten only, and no usage. The usage in kindergarten and first grade group (n = 1,416) consisted of students who used Waterford Early Learning (WEL) during the 2015-2016 (kindergarten) and 2016-2017 (first grade) school years. The usage in kindergarten only group (n = 26) consisted of students who used WEL during the 2015-2016 (kindergarten) school year and had no usage during the 2016-2017 (first grade) school year. The no usage group (n = 31) consisted of students who did not use WEL in either year.

Cohort 1 second grade groups consisted of students with usage in first grade only and students with no usage. The usage in first grade only group (n = 1,529) consisted of students who used WEL during the 2015-2016 (first grade) school year and had no usage during the 2016-2017 (second grade) school year. The no usage group (n = 323) consisted of students who did not use WEL in either year.

Cohort 2 first grade groups consisted of students with usage in kindergarten and first grade, usage in kindergarten only, and no usage. The usage in kindergarten and first grade group (n = 1,381) consisted of students who used WEL during the 2016-2017 (kindergarten) and 2017-2018 (first grade) school years. The usage in kindergarten only group (n = 39) consisted of students who used WEL during the 2016-2017 (kindergarten) school year and had no usage during the 2017-2018 (first grade) school year. The no usage group (n = 32) consisted of students who did not use WEL in either year.

Cohort 2 second grade groups consisted of students with usage in kindergarten and first grade, usage in kindergarten only, usage in first grade only, and no usage. The usage in kindergarten and first grade group (n = 1,235) consisted of students who used WEL during the 2015-2016 (kindergarten) and 2016-2017 (first grade) school years and had no usage during the 2017-2018 (second grade) school year. The usage in kindergarten only group (n = 49) consisted of students who used WEL

during the 2015-2016 (kindergarten) school year and had no usage during either the 2016-2017 (first grade) school year or the 2017-2018 (second grade) school year. The usage in first grade only group (n = 237) consisted of students who used WEL during the 2016-2017 (first grade) school year and had no usage during either the 2015-2016 (kindergarten) school year or the 2017-2018 (second grade) school year. The no usage group (n = 281) consisted of students who did not use WEL in any of the three years.

Students were considered to have used WEL if they had more than 100 minutes of usage in each relevant year. The high usage sub-groups consisted of students with more than 1,000 minutes of usage in each relevant year.

B. Materials

1) Waterford Early Learning (WEL).

Waterford Early Learning offers a comprehensive, computer-adaptive pre-reading and reading 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 reading program.

2) Developmental Reading Assessment (DRA).

The DRA is a standardized reading test used to determine a student's instructional level in reading. The DRA is administered individually to students by teachers and/or literacy coaches. The test identifies whether the student is below, meeting, or exceeding grade level reading expectations.

C. Procedure

Kindergarten students were expected to use WEL for fifteen minutes per day, five days per week, and first grade students were expected to use WEL for thirty minutes per day, five days per week. Usage was tracked within the program and monitored weekly, and total minutes of usage for each school year was calculated. The DRA was administered at the end of the year.

III. Results

A. Group Differences in End of First Grade DRA Scores Using Independent Samples t-tests

Independent samples t-tests examining group differences in DRA end of year scores between the experimental group and the control group were conducted (see Table I).

1) Cohort 1 – Kindergarten and first grade usage compared to no usage.

The experimental group included first grade students who used WEL during kindergarten and first grade. The control group included first grade students who did not use WEL during kindergarten or first grade.

Analysis of end of year scores revealed a significant difference between groups, $t(1, 1445) = -3.80$, $p < .01$, due to higher end of year scores made by Cohort 1 experimental students than by control students. Effect size (d = 0.69).

2) Cohort 2 – Kindergarten and first grade usage compared to no usage.

The experimental group included first grade students who used WEL during kindergarten and first grade. The control group included first grade students who did not use WEL during kindergarten or first grade.

Analysis of end of year scores revealed a significant difference between groups, $t(1, 32) = -3.89$, $p < .01$, due to higher end of year scores made by Cohort 2 experimental students than by control students. Effect size (d = 0.70).

3) Cohort 1 – Usage in kindergarten only compared to no usage.

The experimental group included first grade students who used WEL during kindergarten only. The control group included first grade students who did not use WEL during kindergarten or first grade.

Analysis of end of year scores did not reveal a significant difference between groups, $t(1, 55) = -1.08$, $p = .286$; however, Cohort 1 experimental students had higher end of year scores than control students.

4) Cohort 2 – Usage in kindergarten only compared to no usage.

The experimental group included first grade students who used WEL during kindergarten only. The control group included first grade students who did not use WEL during kindergarten or first grade.

Analysis of end of year scores revealed a significant difference between groups, $t(1, 46) = -4.82$, $p < .01$, due to higher end of year scores made by Cohort 2 experimental students than by control students. Effect size (d = 1.15).

B. Group Differences in End of Second Grade DRA Scores Using Independent Samples t-tests

Independent samples t-tests examining group differences in DRA end of year scores between the experimental group and the control group were conducted (see Table II).

TABLE I. End of First Grade DRA Scores

		Treatment			Control			
		M	*SD*	*N*	*M*	*SD*	*N*	*p*
K and 1st Usage	Cohort 1	18.47	5.12	1416	14.94	5.41	31	.00**
	Cohort 2	18.11	5.10	1381	12.63	7.94	32	.00**
K Only Usage	Cohort 1	16.85	7.92	26	14.94	5.41	31	.29
	Cohort 2	20.15	4.29	39	12.63	7.94	32	.00**

*$p < .05$, **$p < .001$

1) Cohort 2 – Kindergarten and first grade usage compared to no usage

The experimental group included second grade students who used WEL during kindergarten and first grade. The control group included second grade students who did not use WEL during kindergarten, first grade, or second grade.

Analysis of end of year scores revealed a significant difference between groups, $t(1, 356) = -6.70$, $p < .01$, due to higher end of year scores made by Cohort 2 experimental students than by control students. Effect size ($d = 0.44$).

2) Cohort 2 – Usage in kindergarten only compared to no usage.

The experimental group included second grade students who used WEL during kindergarten only. The control group included second grade students who did not use WEL during kindergarten, first grade, or second grade.

Analysis of end of year scores did not reveal a significant difference between groups, $t(1, 328) = -0.49$, $p = .628$; however, Cohort 2 experimental students had higher end of year scores than control.

3) Cohort 1 – Usage in first grade only compared to no usage.

The experimental group included second grade students who used WEL during first grade only. The control group included second grade students who did not use WEL during kindergarten, first grade, or second grade.

Analysis of end of year scores revealed a significant difference between groups, $t(1, 407) = -5.93$, $p < .01$, due to higher end of year scores made by Cohort 1 experimental students than by control students. Effect size ($d = 0.36$).

4) Cohort 2 – Usage in first grade only compared to no usage.

The experimental group included second grade students who used WEL during first grade only. The control group included second grade students who did not use WEL during kindergarten, first grade, or second grade.

Analysis of end of year scores revealed a significant difference between groups, $t(1, 509) = -3.42$, $p < .01$, due to higher end of year scores made by Cohort 2 experimental students than by control students. Effect size ($d = 0.30$).

C. Group Differences in End of First Grade DRA Scores Using Independent Samples t-tests for High Usage vs No Usage Groups

Independent samples *t*-tests examining group differences in DRA end of year scores between the experimental group and the control group were conducted (see Table III).

1) Cohort 1 – Kindergarten and first grade high usage compared to no usage.

The experimental group included first grade students who used WEL during kindergarten and first grade for more than 1,000 minutes in each year. The control group included first grade students who did not use WEL during kindergarten or first grade.

Analysis of end of year scores revealed a significant difference between groups, $t(1, 1123) = -4.62$, $p < .01$, due to higher end of year scores made by Cohort 1 experimental students than by control students. Effect size ($d = 0.84$).

2) Cohort 2 – Kindergarten and first grade high usage compared to no usage.

The experimental group included first grade students who used WEL during kindergarten and first grade for more than 1,000 minutes in each year. The control group included first grade students who did not use WEL during kindergarten or first grade.

TABLE II. END OF SECOND GRADE DRA SCORES

		Treatment			Control			
		M	*SD*	*N*	*M*	*SD*	*N*	*p*
K and 1st Usage	Cohort 2	28.11	5.74	1235	24.88	7.61	281	.00**
K Only Usage	Cohort 2	25.47	9.19	49	24.88	7.61	281	.63
1st Only Usage	Cohort 1	27.15	5.69	1529	24.58	7.34	323	.00**
	Cohort 2	27.11	7.20	237	24.88	7.61	281	.00**

*$p < .05$, **$p < .001$

TABLE III. END OF FIRST GRADE HIGH USAGE DRA SCORES

		Treatment			Control			
		M	*SD*	*N*	*M*	*SD*	*N*	*p*
K and 1st Usage	Cohort 1	19.00	4.82	1094	14.94	5.41	31	.00**
	Cohort 2	18.33	5.10	1158	12.63	7.94	32	.00**
K Only Usage	Cohort 1	19.06	7.61	18	14.94	5.41	31	.03*
	Cohort 2	21.36	3.93	28	12.63	7.94	32	.00**

*$p < .05$, **$p < .001$

Analysis of end of year scores revealed a significant difference between groups, $t(1, 32) = -4.04$, $p < .01$, due to higher end of year scores made by Cohort 2 experimental students than by control students. Effect size ($d = 0.72$).

3) Cohort 1 – High usage in kindergarten only compared to no usage.

The experimental group included first grade students who used WEL during kindergarten only for more than 1,000 minutes. The control group included first grade students who did not use WEL during kindergarten or first grade.

Analysis of end of year scores revealed a significant difference between groups, $t(1, 47) = -2.21$, $p < .05$, due to higher end of year scores made by Cohort 1 experimental students than by control students. Effect size ($d = 0.65$).

4) Cohort 2 – High usage in kindergarten only compared to no usage.

The experimental group included first grade students who used WEL during kindergarten only for more than 1,000 minutes in each year. The control group included first grade students who did not use WEL during kindergarten or first grade.

Analysis of end of year scores revealed a significant difference between groups, $t(1, 47) = -5.50$, $p < .01$, due to higher end of year scores made by Cohort 2 experimental students than by control students. Effect size ($d = 1.42$).

D. *Group Differences in End of Second Grade DRA Scores Using Independent Samples t-tests for High Usage vs No Usage Groups*

Independent samples *t*-tests examining group differences in DRA end of year scores between the experimental group and the control group were conducted (see Table IV).

1) Cohort 2 – Kindergarten and first grade high usage compared to no usage.

The experimental group included second grade students who used WEL during kindergarten and first grade for more than 1,000 minutes in each year. The control group included second grade students who did not use WEL during kindergarten, first grade, or second grade.

Analysis of end of year scores revealed a significant difference between groups, $t(1, 362) = -7.59$, $p < .01$, due to higher end of year scores made by Cohort 2 experimental students than by control students. Effect size ($d = 0.51$).

2) Cohort 2 – High usage in kindergarten only compared to no usage.

The experimental group included second grade students who used WEL during kindergarten only for more than 1,000 minutes. The control group included second grade students who did not use WEL during kindergarten, first grade, or second grade.

Analysis of end of year scores revealed a significant difference between groups, $t(1, 312) = -2.00$, $p < .05$, due to higher end of year scores made by Cohort 2 experimental students than by control students. Effect size ($d = 0.37$).

3) Cohort 1 – High usage in first grade only compared to no usage.

The experimental group included second grade students who used WEL during first grade only for more than 1,000 minutes. The control group included second grade students who did not use WEL during kindergarten, first grade, or second grade.

Analysis of end of year scores revealed a significant difference between groups, $t(1, 418) = -6.78$, $p < .01$, due to higher end of year scores made by Cohort 1 experimental students than by control students. Effect size ($d = 0.42$).

4) Cohort 2 – High usage in first grade only compared to no usage.

The experimental group included second grade students who used WEL during first grade only for more than 1,000 minutes. The control group included second grade students who did not use WEL during kindergarten, first grade, or second grade.

Analysis of end of year scores revealed a significant difference between groups, $t(1, 455) = -2.94$, $p < .01$, due to higher end of year scores made by Cohort 2 experimental students than by control students. Effect size ($d = 0.28$).

TABLE IV. END OF SECOND GRADE HIGH USAGE DRA SCORES

		Treatment			Control			
		M	*SD*	*N*	*M*	*SD*	*N*	*p*
K and 1st Usage	Cohort 2	28.56	5.29	967	24.88	7.61	281	.00**
K Only Usage	Cohort 2	27.70	8.00	33	24.88	7.61	281	.05*
1st Only Usage	Cohort 1	27.54	5.40	1230	24.58	7.34	323	.00**
	Cohort 2	26.99	7.32	176	24.88	7.61	281	.00**

*$p < .05$, **$p < .001$

IV. DISCUSSION

The purpose of the current study was to explore the effects of long-term use of WEL for elementary school students. Results generally supported a beneficial effect of the use of WEL: Across all comparison groups, students who used the program had consistently higher end of year literacy scores compared to students who did not use the program.

This study found that students who used the program only in kindergarten outperformed students in the control group on first and second grade literacy scores. Students still saw meaningful benefit from the program one to two years after they stopped using it, indicating a persistent effect on young students' literacy skills, contrasting previous literature which has indicated that the meaningful effects of CAI intervention tended to be particularly short lived for earlier grades [33], [30]. Moreover, this finding supports a role for CAI in the broader body of literature which stresses the importance of early and effective intervention for young learners.

The findings of the current study also offer support for a dosage effect for CAI intervention: While analysis showed all students significantly outperformed their control counterparts, the largest effect sizes were found for students with high usage. Students with both

sustained and long-term usage of the program improved in a way that students with only long-term usage over the same timeframe did not. This finding is consistent with, and an extension of, prior research [37], [38] demonstrating that a higher dose of a CAI intervention can lead to better results for young students. As this study found evidence for both a lasting benefit of the use of a CAI program and a dosage effect for its use over multiple years, this study endorses both the sustained use and early implementation of CAI programs.

It should be acknowledged briefly that the current study took place within a single school district. This does somewhat limit the generalizability of its findings as it is possible that local demographic, cultural, or socioeconomic confounds may have inadvertently affected the results. The methodology of future research would be made more robust by including a broader sample of multiple school districts. Additionally, expanding the scope of the study to cover students' entire academic careers could offer further insight into the long-term effects of CAI.

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