Making Learning Count: The Effects of Computer-Assisted Instruction on Early Math and Literacy

Haya Shamir[1], Erik Yoder[1], David Pocklington[1], Alexander Houchins[1], and Mikayla Tom[1]

[1] Waterford Institute, Taylorsville, Utah, USA
{hayashamir, erikyoder, davidpocklington, alexanderhouchins, mikaylatom} @waterford.org

Abstract. The current study examines the efficacy of Waterford Early Learning (WEL), a literacy and math computer-assisted instruction (CAI) program. Two groups of students from an Illinois school district (N = 161) participated, an experimental group that used WEL to supplement their traditional kindergarten school year (2023-2024) and a historical control group that did not use WEL during their kindergarten school year (2021-2022). Each group's literacy and math skills were assessed at the beginning and end of their respective kindergarten school years. End-of-year literacy scores for the experimental group were significantly higher than the control group for the overall score and three of the four subskills, with effect sizes ranging from 0.45 to 0.72. End-of-year math scores for the experimental group were also significantly higher than the control group for the overall score and three of the four subskills, with effect sizes ranging from 0.29 to 0.69. These results further demonstrate the efficacy of WEL to improve skills across multiple domains.

Keywords: Literacy, Math, Technology, Kindergarten

1 Introduction

The long-standing rationale which justifies academic research into early education, finding means to improve outcomes for students, is being sidelined. A recent longitudinal study examining students over eight years, starting in prekindergarten, found that the strongest indicator for performance, as measured by GPA in later grades, was the level of educational achievement of the child's mother [1]. The authors went on to suggest that improving maternal education was one of the clearest paths towards increasing long-term learning success. This argument, while accurate to the data being assessed, does not provide an actionable plan to foster learning for students currently in education programs. Any proposal to address learning outcomes through a different population of students misses what the point of research in the field should be.

A review of 14 meta-analyses examining learning interventions found that targeted and systemic interventions directed towards students could improve essential early literacy skills, though the essential criteria of considering who an intervention was intended to work for was not always considered [2]. The actual living, striving, and occasionally struggling pupils are at risk of fading into the foreground in favor of statistical curiosity. It is the responsibility of researchers to center these students and provide educators with the appropriate evidence to select effective and proven tools.

Early interventions can be an effective means of setting up students for future academic success. In a large-scale longitudinal study, children with two years of consistent usage outperformed comparison peers on measures of reading comprehension in the second grade [3]. Early success should, in theory, establish a foundation on which later literacy and math skills can expand. Engagement and enjoyment at early grades positively correlate to later performance. Students who are active and engaged in learning math as early as the second grade tend to have higher math scores in the fourth grade, while students who are bored tend to have worse outcomes [4]. Longitudinal data has indicated that students who had positive experiences in schools had better long-term performance, particularly when transitioning from one grade to another than comparison peers [5]. Early intervention should be able to prime students to succeed in the future. Students reading performance in the third grade was the greatest predictor for performance in the fifth grade, above and beyond the contribution of any other factors considered [6].

Unfortunately, this relationship has not always been borne out by existing research. In a separate longitudinal study, students used supplemental reading activities intending to boost opportunities for purposeful writing [7]. Notably, no differences were found between students who used these interventions and comparison peers on either writing quality or attitude towards writing when assessed two years later. Further, when interventions have been shown to be effective over time, effect sizes have dropped meaningfully [3]. These findings work against a positive feedback loop, necessitating further research.

Evidence surrounding computer-assisted instruction (CAI) as a tool for improving student outcomes has been mixed, reflecting the complexities of intervention research. Past studies found CAI to be ineffective for low and average achievers in mathematics [8], failing to benefit these at-risk populations. However, more recent studies have highlighted a more nuanced view, indicating that CAI can be a useful supplement to traditional instruction [9]. One study found that students who used CAI in the classroom had significant math learning gains and improvements in engagement, motivation, and confidence [10]. These effects were found to be the greatest amongst students with lower levels of math knowledge, contradicting the findings of Afzel et al. [8] and providing hope that CAI could be a useful intervention for all students. Similarly, CAI literacy programs have shown promise in fostering foundational skills [11]. These findings underscore the potential of CAI as a targeted learning tool in the classroom with appropriate integration. Nevertheless, its success hinges on the thoughtful application of evidence-based practices that prioritize the needs and experiences of the students it aims to serve.

The current study examines the efficacy of Waterford Early Learning (WEL), a computer-assisted instruction intervention targeted towards students in kindergarten. It is hypothesized that students who used WEL will benefit from better learning outcomes on measures of (a) literacy and (b) mathematics compared to students in a historical control group.

2 Methods

2.1 Materials

Waterford Early Learning (WEL). This computer-assisted instruction (CAI) program delivers an Early Reading Program (ERP) and an Early Math and Science Program (EMS) designed for early learners that adapt in real time to student performance. WEL presents a variety of educational media (e.g., interactive songs, stories, and activities) and tailors the sequence to match each student's individual abilities and learning pace. Before students continue to more advanced skills, mastery of foundational literacy and math skills is ensured by the program. ERP is designed to help students develop essential literacy skills, including phonological awareness, phonics, fluency, communication, language concepts, and comprehension & vocabulary. EMS focuses on developing students' key mathematical skills, such as number & cardinality, operations & algebraic thinking, measurement and data, geometry, and science. WEL is used as a supplemental curriculum that was built specifically for young learners (preK-2nd grade). Lessons are based on the Science of Reading and designed to be engaging, ensuring that learning is both research-based and fun for the students.

Northwest Evaluation Association (NWEA) Measures of Academic Progress (MAP). The MAP is a valid and reliable assessment intended to measure individual growth and mastery for students in kindergarten through twelfth grade on a range of reading and math skills. The MAP is a computer-adaptive test where each student will get a unique set of test questions based on the student's ability as measured by the previous assessment questions. The reading skills considered relevant to kindergarten students for this study are Overall RIT Reading, Foundational Skills, Language and Writing, Literature and Informational Text, and Vocabulary Use and Functions. The math skills considered relevant to kindergarten students for this study are Overall RIT Math, Operations and Algebraic Thinking, Numbers and Operations, Measurement and Data, and Geometry. Results are scored on a standardized Rasch Unit (RIT) scale [12]. The RIT score measures the student's achievement level and growth over time. This assessment aligns with the skills taught to students in WEL and will reliably measure the students' development in these areas.

2.2 Participants

The sample for this study (N = 161) consisted of kindergarten students from an Illinois school district from the 2021-2022 and 2023-2024 school years. Experimental group students (n = 69) used WEL during their kindergarten year (2023-2024). This study utilized a historical control group of students (n = 92) who did not use WEL during their kindergarten year (2021-2022). The sample consisted primarily of African American/Black and Latino/a students (88% and 10%, respectively). Demographics were similar between the historical control and experimental groups, with the experimental group consisting of 84% African American/Black students and 13% Latino/a students, and the control group consisting of 90% African American/Black students and 7% Latino/a students. As part of the study, the school district approved and signed a research site agreement consenting to provide de-identified student data for analysis.

2.3 Procedure

Experimental group students used WEL in the classroom on a laptop or tablet alongside their school's traditional literacy and math instruction. While WEL learning time was not strictly enforced, students were encouraged to use the program for 15 minutes per day, five days per week. Learning time was tracked automatically within the program and monitored weekly as well as at the end of the school year. On average during the school year, students used ERP for 1,833 minutes with a standard deviation of 659 minutes, while the average usage for EMS was 1,928 minutes with a standard deviation of 647 minutes. Students who did not have WEL learning time received their school's traditional literacy and math classroom instruction. Both groups were assessed with NWEA MAP at the beginning and end of their respective kindergarten years. End-of-year scores were examined covarying for beginning-of-year scores to control for any pre-existing differences between the experimental and control groups.

3 Results

3.1 Literacy Results – Group Differences Using Analysis of Covariance (ANCOVA)

ANCOVAs were conducted to examine group differences in end-of-year reading scores between the experimental and control groups while covarying for beginning-of-year scores (see Fig. 1).

Overall RIT Reading. Analysis of Overall RIT Reading end-of-year scores, covarying for beginning-of-year scores, revealed a significant difference between groups, $F(1, 158) = 15.71$, $p < .001$, due to higher end-of-year scores made by experimental students ($M = 151.95$) than by control students ($M = 146.12$). Effect size ($d = 0.45$).

Foundational Skills. Analysis of Foundational Skills end-of-year scores, covarying for beginning-of-year scores, revealed a significant difference between groups, $F(1, 158) = 22.74$, $p < .001$, due to higher end-of-year scores made by experimental students ($M = 156.32$) than by control students ($M = 145.75$). Effect size ($d = 0.66$).

Language and Writing. Analysis of Language and Writing end-of-year scores, covarying for beginning-of-year scores, revealed a significant difference between groups, $F(1, 158) = 13.78$, $p < .001$, due to higher end-of-year scores made by experimental students ($M = 152.35$) than by control students ($M = 144.91$). Effect size ($d = 0.54$).

Literature and Informational Text. Analysis of Literature and Informational Text end-of-year scores, covarying for beginning-of-year scores, revealed no significant difference between groups, $F(1, 158) = 1.78$, $p < .001$, end-of-year scores of experimental students ($M = 149.11$) were slightly higher than those of control students ($M = 146.38$).

Vocabulary Use and Functions. Analysis of Vocabulary Use and Functions end-of-year scores, covarying for beginning-of-year scores, revealed a significant difference between groups, $F(1, 158) = 29.15$, $p < .001$, due to higher end-of-year scores made by experimental students ($M = 155.29$) than by control students ($M = 144.53$). Effect size ($d = 0.72$).

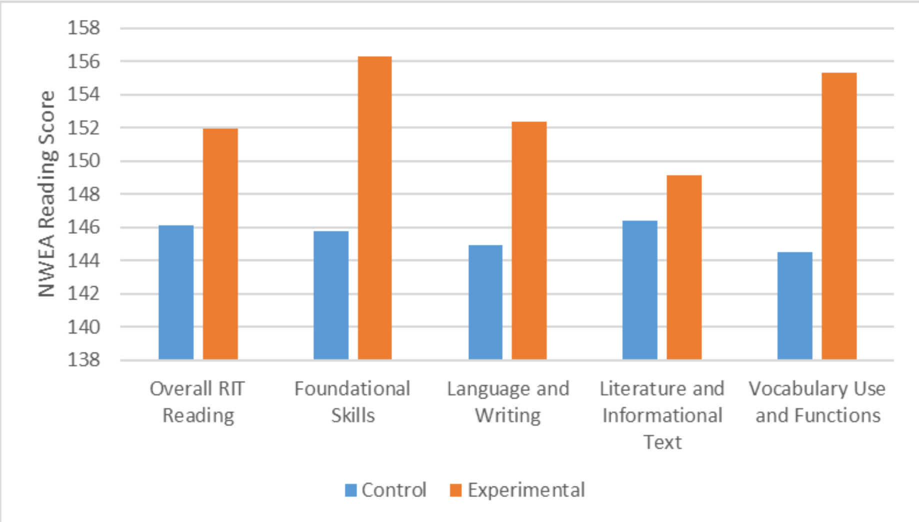

Fig. 1. Kindergarten NWEA MAP Reading End-of-Year Scores Controlling for Beginning-of-Year Scores by Subskill

3.2 Math Results – Group Differences Using Analysis of Covariance (ANCOVA)

ANCOVAs were conducted to examine group differences in end-of-year math scores between the experimental and control groups while covarying for beginning-of-year scores (see Fig. 2).

Overall RIT Math. Analysis of Overall RIT Math end-of-year scores, covarying for beginning-of-year scores, revealed a significant difference between groups, $F(1, 158) = 6.77$, $p < .001$, due to higher end-of-year scores made by experimental students ($M = 158.94$) than by control students ($M = 154.88$). Effect size ($d = 0.30$).

Operations and Algebraic Thinking. Analysis of Operations and Algebraic Thinking end-of-year scores, covarying for beginning-of-year scores, revealed a significant difference between groups, $F(1, 158) = 23.41$, $p < .001$, due to higher end-of-year scores made by experimental students ($M = 165.80$) than by control students ($M = 155.01$). Effect size ($d = 0.69$).

Number and Operations. Analysis of Number and Operations end-of-year scores, covarying for beginning-of-year scores, revealed no significant difference between groups, $F(1, 158) = 0.19$, $p < .001$, end-of-year scores of experimental students (M = 156.15) were slightly higher than those of control students (M = 155.22).

Measurement and Data. Analysis of Measurement and Data end-of-year scores, covarying for beginning-of-year scores, revealed a significant difference between groups, $F(1, 158) = 4.80$, $p < .001$, due to higher end-of-year scores made by experimental students (M = 156.97) than by control students (M = 152.62). Effect size (d = 0.29).

Geometry. Analysis of Geometry end-of-year scores, covarying for beginning-of-year scores, revealed a significant difference between groups, $F(1, 158) = 12.21$, $p < .001$, due to higher end-of-year scores made by experimental students (M = 162.92) than by control students (M = 154.50). Effect size ($d = 0.48$).

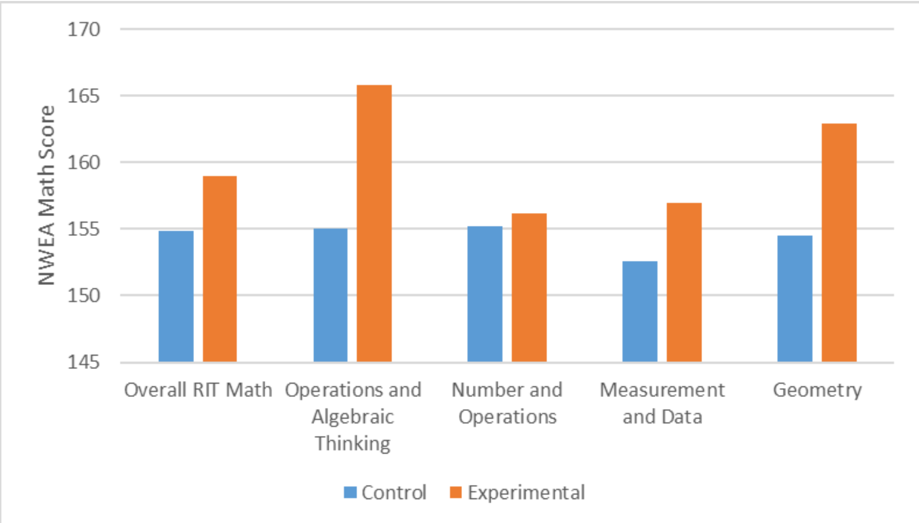

Fig. 2. Kindergarten NWEA MAP Math End-of-Year Scores Controlling for Beginning-of-Year Scores by Subskill

4 Discussion

Results of the current study supported both hypotheses: Students who used WEL during their kindergarten school year achieved higher learning outcomes at the end of the year in both literacy and math skills compared to students in a historical control group who did not use WEL.

After controlling for beginning-of-year scores, differences in end-of-year literacy scores between the experimental and control groups were statistically significant for the overall score and three of the four subskills, with effect sizes ranging from 0.45 to

0.72. WEL demonstrated strong effectiveness in promoting literacy development, particularly in the subskills of foundational skills, language and writing, and vocabulary use and functions. Effect sizes for these subskills were well above the traditional effect size needed for an intervention to be deemed educationally important [13]. While the impact on the literature and informational text subskill was less pronounced, these results suggest that the program excels at building students' core literacy competencies. Literature and informational text skills require students to use higher-order thinking to not only read and understand text but also to apply this understanding to make inferences about the text. It is possible that more extended time spent using WEL could be useful in yielding greater impact in the more complex comprehension and text analysis skills.

Outcomes for math were similarly positive, with statistically significant results for the overall score and three of the four subskills, with effect sizes ranging from 0.29 to 0.69. While students demonstrated significant improvements in key areas of math, such as operations and algebraic thinking, measurement and data, and geometry, the results from the numbers and operations were not significant. The numbers and operations subskill requires students to have a strong conceptual understanding of concepts such as place value, number relationships, and properties of operations. Students must be able to apply this knowledge to a variety of problem types. Due to this, students may require more time to internalize these concepts, leading to longer learning curves. Additionally, these results may have been influenced by the differences in traditional classroom teaching practices between the 2021-2022 and 2023-2024 school years, which could result in students in the experimental and control groups having inconsistent exposure to these skills. However, this does not diminish the potential of WEL to assist young learners with their development of literacy and math skills, as seen by the significant results overall and in the majority of subskills.

These findings support previous research on the positive impact of CAI on early childhood reading [11] and math skills [10]. The programs' use of a wide variety of educational media, such as interactive songs, videos, and activities, is likely to assist in keeping students engaged, as has been observed in previous research [10]. This diverse mix of content, combined with the program's adaptive nature, plays a crucial role in catering to students at different levels and with different learning styles. The positive learning outcomes found from students who used WEL in kindergarten provides promising evidence that the program can help young learners master foundational skills. These early skills have been shown to be predictive of later learning outcomes [6], indicating that WEL can be used to better position learners for future academic success.

One limitation of this study was that students were from one grade within a school district with a single elementary school, resulting in a relatively small sample size. The use of a historical control group is another limitation of this study, as there is potential for differences in teaching practices in the classroom across school years. Future research should include a larger sample across multiple schools with a concurrent control group to further generalize the results. Additionally, measuring student learning outcomes beyond a single school year could demonstrate the long-term impact of CAI interventions.

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