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Exploring the Effects of Computer and Smart Device-Assisted Learning on Students' Achievement: Empirical Evidence from Korea

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Abstract: Computer and Smart Device-assisted Learning (CSDL) has gained increasing attention from educational researchers and practitioners in recent years. However, it remains controversial whether student can benefit from CSDL and what moderator could affect the impact of CSDL. Within the specific context of Korea, where the interest in digital education is steadily increasing, the number of empirical studies exploring the causal effect of CSDL remains relatively scarce. The primary objective of this empirical study was to investigate the impact of CSDL on students' academic achievement in Korea. To achieve this objective, a two-way fixed effect model was employed, utilizing a panel dataset spanning three years derived from the 'Korean Education Longitudinal Study 2013'. The findings revealed a significant positive impact of CSDL on students' Mathematics achievement. Notably, higher income levels, increased availability of computer resources provided by schools, and the implementation of more individualized education were identified as factors that moderate the effect of CSDL on students' achievement levels in Korean and English subjects. These findings underscore the need for an approach that optimizes the educational benefits of CSDL by considering subject-specific characteristics. Furthermore, this study highlights the importance of allocating educational resources, such as computers and smart devices, and integrating individualized educational activities within the classroom environment.

Keywords: computer and smart device-assisted learning; two-way fixed effect model; korean education longitudinal study 2013

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1. Introduction

Following the discourse on educational technology at the Davos Forum in 2016 and the subsequent influence of the COVID-19 pandemic, there has been a notable surge in the inclination towards computer and smart device-supported instruction in classrooms that have embraced Information and Communications Technologies (ICT) [1]. Computer and Smart Device-assisted Learning (CSDL), characterized by the utilization of computers or smart devices for student learning activities, has garnered recognition for its advantage in facilitating self-directed instruction [2–5]. Moreover, it enables individualized instruction by adapting to students' strengths and weaknesses, allowing learning to occur without constant teacher supervision [2,6]. Consequently, CSDL has a potential to positively impact students' academic achievement [7–14].

In response to the escalating interest, the Korean Ministry of Education (MOE) has endeavored to fortify the utilization of CSDL and ICT in education. The MOE established an integrated K-Edu platform and an e-learning center video class system, with the objective of facilitating interactive distance learning. Additionally, the MOE launched a digital content platform, called 'Connect (ITDA)', designed to provide educational assistance to teachers [1]. Furthermore, the Korean MOE announced a comprehensive plan to foster digital talent and support digital education in order to improve competencies for the burgeoning digital industry in 2022 [15]. The plan prominently underscores the pivotal significance of fostering digital literacy, enhancing AI and software education, and improving the digital expertise of teachers as key policy priorities. Particularly

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noteworthy is the advent and utilization of an AI-powered learning tutoring system as an assistant teacher. This pioneering project serves as a tangible manifestation of the recent upsurge in policy interest surrounding CSDL in Korea.

However, a counterargument challenges the notion that CSDL effectively enhances students' academic achievement. Bulman and Fairlie [2] suggest that educational activities conducted through computers could potentially diminish the educational impact of traditional teacher-centered lectures or student-centered classes, which have traditionally been the norm in the classroom. Thus, the educational effect of CSDL may not yield positive outcomes if the investment in such technology surpasses the impact of investment in traditional teachers, textbooks, and other educational resources. Similarly, Belo et al. [16] posit that if students utilize computers or smart devices for non-learning activities, such as gaming, it may not contribute to improved academic achievement. Furthermore, Agasisti et al. [17] reveal a negative association between the use of computers for homework and students' academic achievement.

In summary, the theoretical relationship between CSDL and students' achievement can be represented as depicted in Figure 1. Strengthening CSDL, which entails self-directed and individualized learning, holds promise for enhancing students' academic achievement. However, it is crucial to consider potential drawbacks. Firstly, an increased focus on investing in CSDL may lead to a reduction in investment in traditional educational resources, thereby offsetting the educational effects associated with these resources. Secondly, ineffective utilization of computers and smart devices, such as engaging in network activities, watching videos, and gaming, can divert attention from their intended purpose of facilitating learning [18]. Therefore, it becomes essential to empirically examine the impact of learning activities involving computers and smart devices on the improvement of academic achievement.

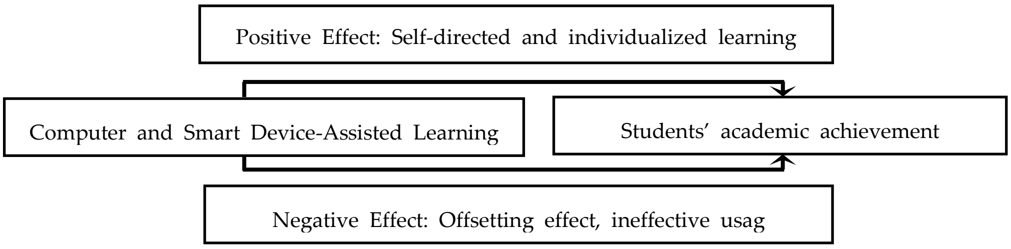

Figure 1. Theoretical relationship between Computer and Smart Device-assisted Learning and achievement.

Within this context, prior studies have endeavored to analyze the educational impact of CSDL [6,11–14,19–25]. The existing literature has predominantly investigated the effects of educational activities utilizing computers and smart devices through various analytical methods, such as experimental studies, fixed-effect models, and instrumental variables. However, these studies have produced inconsistent findings. While some studies found statistically significant and positive impact of CSDL on students' academic achievement [6,11–14], other papers showed insignificant effect of CSDL [23–25].

Similarly, in the Korean context, attempts have been made to analyze the effects of educational activities employing computers and smart devices. According to most of these studies, educational activities involving computers and smart devices generally exhibit a positive influence on learning immersion, learning attitude, and achievement levels [26–29]. Nevertheless, these studies primarily focused on specific school-based educational programs with small sample, limiting the generalizability of the impact of computer and smart device use for learning purposes.

Furthermore, previous studies conducted in Korea to evaluate the effectiveness of education utilizing computer and smart devices typically developed educational programs using smart devices and employed an experimental design with an experimental group and a control group [30–33]. However, when implementing experimental research, ensuring causal validity through random assignment is crucial. Randomly assigning participants to the experimental and control groups and ensuring homogeneity between these groups are essential factors for causal inference. Nonetheless, existing literature in Korea has faced limitations in terms of securing randomness and homogeneity among groups due to convenient sampling methods and small sample sizes.

Therefore, this study aims to comprehensively examine the educational effects of CSDL. Recognizing the challenges in generalizing analysis results and verifying group homogeneity, this study seeks to infer the causal effect of utilizing computers and smart devices for learning by employing a representative large dataset and conducting panel regression analysis.

On the other hand, it has been observed that the effects of educational programs or policies can vary among schools and students [34]. In light of this, studies have been conducted to analyze the differential effects of CSDL, exploring how these effects vary based on individual student or school characteristics. However, the results of these studies have also exhibited inconsistencies [35–37]. Therefore, this study aims to address the overlooked differential effects of CSDL by considering student and school characteristics, such as socioeconomic background, availability of computer resources in schools, and the extent of individualized instruction referring to existing literature [6,9,38,39].

Based on these results, this study seeks to derive implications for the effective utilization of computers and smart devices in classrooms. The research questions addressed are as follows: 1) How does Computer and Smart Device-assisted Learning affect students' academic achievement? 2) How do the educational effects of Computer and Smart Device-assisted Learning vary based on student and school characteristics?

2. Materials and Methods

2.1. Materials

This study utilizes data from the 'Korean Education Longitudinal Study (KELS) 2013', which was conducted and managed by the Korea Educational Development Institute (KEDI), to investigate the impact of computer and smart device-assisted learning on students' academic achievement. The target population of KELS 2013 comprised 5th-grade Korean elementary school students in 2013, totaling 524,111 students from 5,509 elementary schools. Through stratified cluster random sampling, a sample of 7,324 students from 242 elementary schools was selected for participation in KELS 2013, and these students have been surveyed annually. For the purposes of this analysis, data from three years of KELS 2013, spanning from the 3rd survey year (2015, 1st grade of middle school) to the 5th survey year (2017, 3rd grade of middle school), were utilized.

From the students who completed the survey for all three years (2015-2017), a sample of 3,420 students without any missing values was selected. This sample was used to construct a balanced panel dataset, which was subsequently employed for the analysis in this study. Ultimately, the number of samples analyzed in this study was 3,420, with a total number of observations amounting to 10,260.

2.2. Method

To address the research questions stated above, this study employed the variables of "1) use and 2) usage time of computer and smart device" as treatment variables. The relevant data regarding computer and smart device usage and time were collected by extracting specific questions from the student questionnaire. These questions aimed to capture the average daily duration of computer and smart device usage in the following five areas: 1) study and homework, 2) information search and data utilization unrelated to learning, 3) texting, chatting, messaging, emailing, and phone calls, 4) gaming and entertainment, and 5) participation in clubs, cafes, and community activities. Variables were constructed to determine whether computers and smart devices were used for studying and completing homework, as well as to measure the average time dedicated to these activities.

Additionally, this study utilized individual students' academic achievement scores as the dependent variables. To facilitate panel regression analysis, the vertical scale scores of academic achievement in Korean, English, and Mathematics provided by KELS 2013 were utilized. Furthermore, various student and school-specific factors that influence students' academic

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achievement were transformed into variables and included in the regression model referring previous studies regarding [40–46]. The student characteristics variables encompassed factors such as gender, parent support for the child, self-study time, expected education level, both parents' living situation, average monthly household income, average monthly private tutoring expenses, class immersion by subjects, and participation in cultural activities. Moreover, the school characteristics variables included factors such as location, teacher enthusiasm, individualized instruction, interactive teaching, establishment type, co-educational status, number of computers for education per pupil, teaching and learning space, school size, average career experience of teachers, proportion of teachers with master's and doctoral degrees, and the presence of female principals. For a comprehensive overview, the Table 1 below presents the variables utilized in this study along with corresponding explanations.

Table 1. Definition and descriptive statistics of key variables.

variable		Description	Mean	Std. dev.
Dependent variables	Korean achievement score	Vertical scale scores of achievement in Korean language	241.32	48.05
	English achievement score	Vertical scale scores of achievement in English language	257.90	50.89
	Mathematics achievement score	Vertical scale scores of achievement in Mathematics	244.79	50.86
Treatment variables	Use of computer and smart device for learning	Whether or not computers and smart devices were used for study and homework	0.88	-
	Usage time of computer and smart device for learning	the amount of time computers and smart devices were used for study and homework per day(hours)	0.76	0.75
Student characteristics	Gender	1 if respondent is female; otherwise, 0	0.52	-
	Parent support for child	average of 8 items regarding parental support for child (5 Likert scale)	3.41	0.86
	Self-study	learning time by alone(hours)	1.47	1.21
	Expected education	Expected years of schooling	13.99	5.91
	Both parents living	1 if a student lives with biological parents; otherwise, 0	0.87	0.33
	ln(average monthly household income)	Natural log of average monthly household income	6.18	0.53
	ln(average monthly private tutoring expense)	Natural log of average monthly private tutoring expense	6.01	0.94
	Korean class immersion	Student immersion time in Korean language class (minutes)	32.1	10.5
	English class immersion	Student immersion time in English language class (minutes)	32.1	11.1
	Mathematics class immersion	Student immersion time in Mathematics class (minutes)	32.2	11.3
	Cultural activities	The number of cultural activities at home	4.36	2.79
School characteristics	Location1	Dummy variable indicating school location (Capital)	0.19	-
	Location2	Dummy variable indicating school location (Metropolitan)	0.26	-
	Location3	Dummy variable indicating school location (Middle)	0.43	-
	Location4	Dummy variable indicating school location (Small)	0.12	-
	Teacher enthusiasm	Average of 9 items regarding teacher enthusiasm (5 Likert scale)	3.73	0.51

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	Individualized instruction	Average of 4 items regarding personalized teaching (5 Likert scale)	3.60	0.82
	Interactive teaching	Average of 4 items regarding interactive teaching (5 Likert scale)	3.66	0.82
	Establishment type	1 if school is private; otherwise, 0	0.18	-
	Co-education	1 if school is coeducation; otherwise, 0	0.74	-
	Number of computers for education	Number of computers for education per pupil	0.13	0.13
	Teaching and learning space	Number of teaching and learning spaces (subject class, special class, etc.)	12.78	6.70
	School size	Number of students in school	704.69	279.23
	Average career experience of teachers	Average years of teacher experience	16.42	3.29
	Proportion of teachers with graduate school degrees	% of teachers with master's and doctoral degrees	36.60	9.46
	Presence of female principals	1 if female principal; otherwise, 0	0.23	-

In order to empirically investigate the educational effects of CSDL, this study employed a two-way fixed effect model. The model incorporated student fixed effects, which are unobservable, as well as unique year fixed effects within each specific year. The estimated regression function can be represented as follows:

$$Y_{ist} = \alpha + \beta SMART_{ist} + \gamma STU_{ist} + \delta SCH_{st} + \mu_i + \lambda_t + \varepsilon_{ist}$$

Y_{ist} is the dependent variable indicating the academic achievement scores, where the subscript 'i', 's', and 't' refer to individual, school, and year, respectively. $SMART_{ist}$ is the treatment variable, signifies the use (or usage time) of computers and smart devices for learning. STU_{ist} and SCH_{st} indicate student and school characteristics, respectively. μ_i represents the individual student's fixed effect, λ_t denotes the unique year fixed effect, and ε_{ist} is the stochastic error term.

The regression coefficient β indicates the extent of change in academic achievement attributed to the utilization of computers and smart devices for learning while controlling for other variables. Moreover, to examine how the educational effect of using computer and smart devices for learning varies based on student and school characteristics, the aforementioned equation includes an interaction term with treatment variables and student and school characteristics variables.

3. Results

3.1. The effect of compter and smart device-assisted learing on students' academic achievement

The estimation results concerning the effects of CSDL on students' academic achievement, controlling for student and year fixed effects, are presented in Table 2. The findings revealed a statistically significant and positive impact of CSDL on students' Mathematics achievement. Specifically, the utilization of computers and smart devices for learning demonstrated a positive impact on Mathematics achievement, with an increase of 1.038 points in the achievement score. In contrast, no significant effects were observed for Korean or English subjects. The results indicate that the positive effect of CSDL on students' academic achievement is most prominent in the subject of Mathematics. However,

Table 2. The effect of computer and smart device assisted learning on academic achievement.

	Korean	**English**	**Mathematics**	**Korean**	**English**	**Mathematics**
Use of computer and smart device for learning	-0.110 (0.557)	-0.008 (0.515)	1.038* (0.532)	-	-	-
Usage time of computer and smart device for learning	-	-	-	-0.197 (0.502)	-0.161 (0.469)	0.485 (0.482)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Student-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	10,260	10,260	10,260	10,260	10,260	10,260

Note. Standard errors are in parentheses. Dependent variables the vertical scale scores of Korean, English, Mathematics achievement. The model includes various control variables, such as gender, parent support for child, self-study time, expected education, both parents living, average monthly household income, average monthly private tutoring expenses, class immersion by subjects, cultural activities, school location, teacher enthusiasm, individualized instruction, interactive teaching, establishment type, co-educational status, number of computers for education, teaching and learning space, school size, average career experience of teachers, proportion of teachers with master's and doctoral degrees, and the presence of female principals. However, due to the page limitation, these results have not been reported. 'Yes' means that these control variables are included. And Significant levels are *** p<0.01, ** p<0.05, * p<0.1.

To further investigate whether the educational effect of using computers and smart devices varies based on usage time, the same analysis was conducted using Korean, English, and Mathematics achievement scores as dependent variables, while incorporating variables related to the duration of CSDL. The results of the analysis indicate that the amount of time spent utilizing computers and smart devices for learning did not have a statistically significant effect on students' academic achievement.

3.2. The differential effects of compter and smart device assisted learning

The preceding analysis results pertain to the overall average effect of CSDL on academic achievement. However, it is crucial to also explore the educational effect in specific contexts. Therefore, this study aimed to investigate the differential effects of CSDL based on the characteristics of students and schools. It is acknowledged that these effects may vary depending on factors such as household income level, school support for computers and smart devices, and the extent of individualized instruction, which has garnered significant attention in recent years [9,37,38]. To examine these variations, a two-way fixed effect model was employed to assess the differential effects of using computers and smart devices for learning within the aforementioned three dimensions.

3.2.1. The differential effect depending on household income

Initially, this study examined the differential effects of using computers and smart devices for learning based on the household income level. To investigate those heterogeneous effects, the analysis included interaction terms involving variables related to computer and smart device usage for learning and the average monthly household income. The analysis utilized achievement scores in Korean, English, and Mathematics as dependent variables. The results, as presented in Table 3, indicate that a differential effect of CSDL based on income level was observed when analyzing Korean language achievement as the dependent variable. Specifically, while holding other variables constant, a 1 percent increase in average monthly household income was associated with an approximate increase of 0.015 points in the effect of CSDL on Korean language achievement. It is important to note that this finding is specific to the Korean language subject, emphasizing the variability in the effects of CSDL based on income level.

Table 3. The interaction effect of computer and smart device usage and household income.

	Korean	English	Mathematics	Korean	English	Mathematics
ln(average monthly household income)	-1.293 (1.765)	1.458 (1.389)	0.353 (1.223)	-0.941 (0.714)	1.188 (1.374)	-0.012 (1.205)
Use of computer and smart device for learning	-9.307* (5.595)	4.960 (5.633)	-4.062 (5.442)	-	-	-
Use of computer and smart device for learning x ln(average monthly household income)	1.482* (0.900)	-0.807 (0.911)	0.826 (0.883)	-	-	-
Usage time of computer and smart device for learning	-	-	-	-6.614 (5.249)	2.728 (5.144)	-7.032 (5.078)
Usage time of computer and smart device for learning x ln(average monthly household income)	-	-	-	1.031 (0.840)	-0.469 (0.823)	1.213 (0.816)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Student-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	10,260	10,260	10,260	10,260	10,260	10,260

Note. Standard errors are in parentheses. Dependent variables the vertical scale scores of Korean, English, Mathematics achievement. The model includes various control variables, such as gender, parent support for child, self-study time, expected education, both parents living, average monthly private tutoring expenses, class immersion by subjects, cultural activities, school location, teacher enthusiasm, individualized instruction, interactive teaching, establishment type, co-educational status, number of computers for education, teaching and learning space, school size, average career experience of teachers, proportion of teachers with master's and doctoral degrees, and the presence of female principals. However, due to the page limitation, these results have not been reported. 'Yes' means that these control variables are included. And Significant levels are *** p<0.01, ** p<0.05, * p<0.1.

These findings, while specific to the Korean subject, imply that the effects of CSDL can be heterogeneous depending on the level of household income. Considering that household income can amplify the effect of CSDL on Korean achievement score, policy interventions are imperative to mitigate the disparities in the effectiveness of CSDL based on income levels.

In contrast, the analysis revealed that the interaction coefficients between the duration of CSDL and average monthly household income were statistically insignificant. This suggests that there were no differentiated effects of CSDL intensity on students' academic achievement regarding household income level.

3.2.2. The differential effect depending on the number of computers for education

Subsequently, this study proceeded to investigate the differential effects CSDL based on the level of ICT infrastructure in individual schools. To accomplish this objective, the same estimation model as presented in Table 3 was utilized, incorporating an interaction terms between variables related to computer and smart device usage for learning and the number of computers per pupil in the school. Table 4 unveils a heterogeneous effect of CSDL with respect to the number of computers per student, specifically in the context of the English subject. Controlling for other variables, each 1-unit increase in the number of computers per student was associated with an approximate increase of 5.299 points in the impact of CSDL on English achievement.

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Table 4. The interaction effect of computer and smart device usage and the number of computers.

	Korean	English	Mathematics	Korean	English	Mathematics
number of computers for education per pupil	-11.570 (7.660)	-12.700* (6.482)	-4.735 (5.527)	-12.535* (7.498)	-13.502** (6.401)	-5.771 (5.460)
Use of computer and smart device for learning	-0.802 (0.747)	-0.710 (0.666)	1.080 (0.668)	-	-	-
use of computer and smart device for learning x number of computers for education per pupil	5.127 (3.800)	5.299* (3.098)	-0.262 (2.802)	-	-	-
Usage time of computer and smart device for learning	-	-	-	-0.995 (0.668)	-0.949 (0.616)	0.373 (0.614)
Usage time of computer and smart device for learning x number of computers for education per pupil	-	-	-	6.213* (3.373)	6.092* (2.697)	0.926 (2.591)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Student-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	10,260	10,260	10,260	10,260	10,260	10,260

Note. Standard errors are in parentheses. Dependent variables the vertical scale scores of Korean, English, Mathematics achievement. The model includes various control variables, such as gender, parent support for child, self-study time, expected education, both parents living, average monthly household income, average monthly private tutoring expenses, class immersion by subjects, cultural activities, school location, teacher enthusiasm, individualized instruction, interactive teaching, establishment type, co-educational status, teaching and learning space, school size, average career experience of teachers, proportion of teachers with master's and doctoral degrees, and the presence of female principals. However, due to the page limitation, these results have not been reported. 'Yes' means that these control variables are included. And Significant levels are *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Moreover, when examining the relationship between the time spent on CSDL and Korean and English achievement scores, differential effects were observed according to the number of computers per student. Specifically, for each additional unit increase in the number of computers per student, while holding other variables constant, the influence of time spent using computers and smart devices for learning on the Korean language score exhibited an approximate increase of 6.213 points. Similarly, each 1-unit increase in the number of computers per student was associated with an increase of 6.092 points in the impact of CSDL on English achievement scores. This suggests that there were differentiated effects of CSDL intensity on students' academic achievement in the subject of Korean and English. These findings indicate that the impact of CSDL on academic achievement can vary depending on the level of school ICT infrastructure in terms of hardware.

3.2.3. The differential effect depending on the degree of individualized education

Lastly, this study investigated the differential effects of CSDL based on the extent of individualized instruction. The results, presented in Table 5, revealed a heterogeneous effect when examining the association between computer and smart device usage for learning and English achievement. Notably, it was observed that as the level of individualized instruction increased, the impact of CSDL on the English achievement score increased by approximately 1.031 points.

Table 5. The interaction effect of computer and smart device usage and individualized instruction.

	Korean	English	Mathematics	Korean	English	Mathematics
individualized instruction	-0.141 (0.861)	-0.569 (0.786)	-0.539 (0.862)	0.102 (0.849)	-0.224 (0.782)	-0.552 (0.864)
Use of computer and smart device for learning	-0.923 (2.351)	-3.811* (2.150)	-0.368 (2.330)	-	-	-
use of computer and smart device for learning x individualized instruction	0.213 (0.630)	1.031* (0.565)	0.386 (0.616)	-	-	-
Usage time of computer and smart device for learning	-	-	-	0.225 (2.084)	-1.965 (1.957)	-0.782 (2.039)
Usage time of computer and smart device for learning x individualized instruction	-	-	-	-0.122 (0.546)	0.483 (0.511)	0.345 (0.536)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Student-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	10,260	10,260	10,260	10,260	10,260	10,260

Note. Standard errors are in parentheses. Dependent variables the vertical scale scores of Korean, English, Mathematics achievement. The model includes various control variables, such as gender, parent support for child, self-study time, expected education, both parents living, average monthly household income, average monthly private tutoring expenses, class immersion by subjects, cultural activities, school location, teacher enthusiasm, interactive teaching, establishment type, co-educational status, number of computers for education, teaching and learning space, school size, average career experience of teachers, proportion of teachers with master's and doctoral degrees, and the presence of female principals. However, due to the page limitation, these results have not been reported. 'Yes' means that these control variables are included. And Significant levels are *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

These findings, while specific to the English subject, suggest that the effects of utilizing computers and smart devices for learning can vary depending on the degree of individualized instruction in the classroom. The extent of individualized instruction plays a crucial role in shaping the relationship between CSDL and English outcomes.

On the contrary, the analysis showed that the interaction coefficients between the duration of CSDL and the degree of individualized instruction were not statistically significant. This suggests that there were no differential effects of CSDL intensity on students' academic achievement according to extent of the individualized instruction.

4. Discussion

The findings of this study reveal that CSDL has a positive effect on improving math achievement scores. This finding indicates that the use of computers or smart devices for learning exhibited statistically significant effects, primarily in specific subjects. However, it is noteworthy that the size of these effects was not substantial, and their impact was observed within a limited range. Additionally, there is no statistically significant effect when analyzing the intensity effect based on the duration of computer and smart device use for learning. These findings are consistent with previous studies. Cheung and Slavin [47] implemented a meta-analysis on the effect of computer-assisted instruction and concluded that educational technology applications produced a positive but small effect. Higgins et al. [48] also found that there were small positive associations between the use of technology in education and students' attainment. Similarly, Slavin et al. [49,50] observed a small effect size of computer-based instruction, and Rakes et al. [51] and Li and Ma [52] reported statistically significant but modest effect sizes in relation to computer technology's influence on mathematics achievement.

Furthermore, this study identifies that the effect of using computers and smart devices to enhance academic achievement varies depending on student and school characteristics. Specifically, higher income levels, increased provision of computer devices by schools, and more active implementation of individualized education contribute to a greater improvement in academic achievement through the use of computers and smart devices. These findings align with previous research by Yang and Lee [53], which explores the influence of socio-economic conditions on the relationship between educational resources and academic achievement. One possible explanation for the observed heterogeneity based on income levels is the difference in the quality of the learning content accessed through computers and smart devices. While there may not be significant differences in the amount of time spent using these devices between high-income and low-income groups, variations in the quality of the learning content accessed through these devices can account for the differential effects based on income levels. Further research is needed to empirically validate these hypotheses.

Notably, the research results underscore the significance of educational information hardware infrastructure in schools and individualized education within classrooms to enhance the educational effect of CSDL. Previous researchers, such as Carlson [54], Trucano [55], UNESCO [56], UNICEF [57], and Kaye et al. [58] suggest that appropriate school infrastructure is one of the key factors that should be considered to either facilitate or impede learning outcomes through computer-assisted instruction. Similarly, Barrow et al. [6], Heath and Ravists [59], Lepper and Gurtner [60], and Means and Olson [61] suggest utilization of computers and smart devices for learning offers more individualized instruction, and allows students to learn at their own pace, therefore CSDL with individualized instruction could be more beneficial for students' achievement. Therefore, in order to improve the educational effectiveness of using educational computers and smart devices, it is crucial to establish adequate infrastructure for these devices in classrooms and promote individualized education practices within classrooms.

Based on these findings, several key discussions emerge. Firstly, considering the positive effect of CSDL, it is crucial to adopt an approach that takes into account subject-specific characteristics and that maximizes the effect of CSDL on students' academic achievement when utilizing computers and smart devices for learning, and formulating related policies. In Korea, ongoing efforts are being made to ensure students' basic academic proficiency through the utilization of computers and smart devices for diagnosing underperforming students and implementing targeted remedial programs tailored to each subject. However, additional initiatives are needed to augment the overall educational impact of CSDL. These initiatives encompass modularizing the mathematics curriculum and facilitating comprehensive learning aligned with the modularized curriculum, as well as integrating Artificial Intelligence (AI) to deliver student-customized curricula. Specifically, by providing support to students in completing an individualized mathematics curriculum that aligns with their proficiency level through CSDL, it is anticipated that the effectiveness of incorporating computers and smart devices in mathematics education will be enhanced, thereby fostering improved academic achievement.

Secondly, recognizing that the effects of CSDL may differentiate based on family income level, school information infrastructure, and the degree of individualized instruction within classrooms, it is needed to increase school-level support for computer and smart device utilization for learning, with a particular focus on promoting individualized education practices. In Korea, there has been a notable emphasis on software support for the establishment of educational information infrastructure in schools, while hardware support remains relatively limited, focusing on specific model schools. However, considering the findings of this study, it is needed to expand the ICT infrastructure for education to reinforce ICT convergence education and students' digital competencies across all schools nationwide. And, the discourse on equitable educational opportunities in the digital age is closely intertwined with the accessibility of computers and smart devices for learning. Thus, it is imperative to reconsider a comprehensive support approach that expands ICT assistance in educational infrastructure for all students, ensuring universal access.

Lastly, in addition to content and hardware development, it is essential to enhance teachers' capacity for individualized education that effectively utilizes these resources. The results of this study suggest that an approach linked with individualized instruction is expected to be more effective in strengthening the impact of CSDL. Therefore, extending the discussion of Individualized Education Plans (IEPs), which have primarily been applied in special education, to general primary and secondary education, while strengthening teacher professionalism and providing adequate support.

In addition to the issues covered in this study, it is important to take into account some other risks and benefits associated with CSDL, such as cyber-bullying and accessing unsafe material, as well as developing digital skills relevant to the 21st century labor market. When implementing CSDL program or policies, it is crucial to assess these risks and opportunities.

5. Conclusions

The objective of this study is to empirically examine the impact of CSDL on academic achievement. To accomplish this objective, this study analyzed both the average effect of computer and smart device use on academic achievement and the differential effects based on student and school characteristics. Panel data from the Korean Education Longitudinal Study(KELS) 2013, covering the 1st to 3rd grades of middle school, were used for empirical analysis, employing a two-way fixed-effect model that controls for student and year fixed effects.

To conclude, this study provides empirical evidence on the impact of CSDL on academic achievement. The findings highlight the statistically significant positive effect of such learning methods on math achievement scores. However, the effect size is relatively modest, and the duration of device use does not have a significant impact on academic achievement. Furthermore, the study reveals that the effects vary based on student and school characteristics, including income levels, school information infrastructure, and the degree of individualized instruction. It emphasizes the importance of educational hardware infrastructure and individualized education practices for enhancing the educational effectiveness of CSDL.

Based on these findings, it is recommended to consider subject-specific characteristics when formulating policies related to the educational use of computers and smart devices, particularly in mathematics. School-level support and instruction should be increased to facilitate computer and smart device usage, with a focus on promoting individualized education practices. Additionally, efforts should be made to enhance teachers' capacity for individualized instruction and to address the potential risks and benefits associated with CSDL.

Further research is needed to validate the findings and explore additional factors that may influence the impact of CSDL on academic achievement. Additionally, it is also needed to undertake future research that delves into the present state of the widening digital education disparity in the post COVID-19 era and to devise viable remedies to effectively tackle this critical concern. By addressing these issues, policymakers, educators, and researchers can work together to maximize the educational benefits of utilizing computers and smart devices in learning environments while mitigating potential risks.

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