Humanities & Social Sciences Communications

ARTICLE

https://doi.org/10.1057/s41599-025-04399-6 OPEN

The causal relationship between digital literacy and students' academic achievement: a meta-analysis

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This meta-analysis focuses on the relationship between digital literacy (DL) and academic achievement. The 35 independent effect sizes that were collected were analyzed using Comprehensive Meta-analysis (CMA) software version 2.0, and the results showed a significant, medium positive correlation between DL and academic achievement. In addition, there were significant differences in the correlation between DL and academic achievement among students of different grade levels, orientations of DL, subjects, sampling methods, and genders. We suggest that (1) schools should develop students' DL by strengthening the construction of a digital learning environment; (2) teachers and parents should give more guidance to primary and middle school students on the application of digital tools, making them aware of the advantages and disadvantages of digital technology for learning; and (3) students should have general digital operation skills and further master the special methods and learning models of digital technology applied to different subjects. Finally, although the relationship between DL and academic achievement was moderated by gender, with a stronger link observed in males than females, there are no full gender ratios of participants from the samples. Therefore, the relationship between DL and achievement across genders needs to be further verified in future research.

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Introduction

With the rapid advancement and wide application of various information and communication technologies, society has become a technologically rich digital environment (Bilan et al. 2023; Timotheou et al. 2023; Jiang et al. 2024; Islam et al. 2024; Longwei et al. 2023). People are increasingly using digital technology to deal with information and solve problems. Digital literacy (DL) has become a new core skill in work, learning, and communication (Farias-Gaytan et al. 2022; Pangrazio and Sefton-Green, 2021; Porat et al. 2018). Educational settings are also being changed by advanced digital technology, and a variety of digital teaching and learning modes have been devised (Alenezi, 2023; Hakimi et al. 2024). Students have participated in various learning activities supported by digital technology, such as accessing learning management systems, searching online learning resources, reading e-books, developing online cooperation, and participating in internet-based learning forums (Culduz, 2024; Riyanti et al. 2023). With the application of digital technology in learning, more and more researchers have determined that DL is becoming a prerequisite for students to learn effectively (Peláez et al. 2020), and excellent academic performance can support students in securing better employment opportunities. Therefore, it is necessary for educators to ask: Is DL related to students' academic achievement in the digital era? This study aims to answer this question.

Literature review

In previous studies, some used experimental research methods to explore the relationship between DL and academic achievement. For instance, Akhyar et al. (2021) used random sampling techniques to identify 348 middle school students participating in online learning and then adopted questionnaires and science learning outcome tests to collect data. The quantitative analysis results show that DL has a positive and significant impact on middle school students' online learning outcomes in science. However, there are different results due to variations in grade levels, different orientations of DL, genders, and other influencing factors. For example, Falode et al. (2017) selected 100 college students with a background in Information and Communication Technology to participate in a teaching experiment based on digital environments using a multi-stage sampling procedure. They collected experimental data on the students' digital skills and academic performance through questionnaires and academic tests. The results of the Pearson product–moment correlation analysis revealed no significant relationship between students' digital skills and academic performance. Meta-analysis is a further statistical analysis of existing research results in a certain research field, aiming to integrate previous findings (Hedges and Olkin, 2014) to obtain more comprehensive research results (Wisniewski et al. 2020). To further determine the relationship between DL and students' academic achievement, as well as to identify the influencing factors that affect the relationship between DL and academic achievement, this study used the meta-analysis approach.

Digital literacy. DL is a fundamental capability to utilize digital technologies to access, evaluate, create, and communicate information safely and responsibly, as well as to solve basic problems across all aspects of life (Puniatmaja et al. 2024; Smith et al. 2020). Individuals with DL can engage in activities and interactions in digital environments as well as efficiently and freely access the knowledge present in these environments (Pangrazio et al. 2020; Van Laar et al. 2017). Different terms were used to refer to DL in different research fields, such as media literacy, internet literacy, ICT Literacy, information literacy, e-literacy, technology literacy, etc. (Martínez-Bravo et al. 2020). These different conceptual formulations encompass the researchers' two categories of views on DL, either as a collection of various technical operational skills, or as a combination of technology, cognition, and socio-emotional skills. For instance, The International Computer and Information Literacy Study (ICILS) focused on the operational skills in its DL assessment framework for adolescents. They defined DL as "an essential ability for individuals to effectively participate in families, schools, companies, and communities," specifically including "understanding computer applications, collecting information, generating information and digital communications" (Fraillon et al. 2019). In contrast, another DL conceptual model from the European Commission Joint Research Centre consists of three development dimensions—technical, cognitive, and social-emotional (Martínez-Bravo et al. 2022). This conceptual model not only focuses on operational skills in digital technology but also emphasizes the communication and cooperation skills of applying digital technology and the strategy of using digital technology. In recent years, with the deepening of researchers' understanding of the impact of digital technology on society, the connotation of DL has also evolved. This includes not only the technical skill dimension of using software and digital equipment but also the cognitive and socio-emotional dimensions of solving problems in a digital environment (Palacios Garay et al. 2021; Park et al. 2021).

Although digital technology provides students with a new learning environment and rich learning resources, there is no guarantee that students will use it to achieve academic success (Song et al. 2018). This is because not every student has the knowledge, skills, and perspectives that enable them to participate critically in digital technology and use it effectively (Becta, 2010; Štemberger and Konrad, 2021). For students to succeed in the digital learning environment, they need to possess various digital skills, including communication, collaboration, organization, critical reading, and creative expression through digital tools (Ukwoma et al. 2016). Specifically, DL will enable students to effectively and safely navigate the digital space, facilitate their access to learning resources, assist them in self-directed learning, and enhance their understanding of knowledge (Greene et al. 2014; Moldavan et al. 2022; Stahler-Sholk, 2015).

Academic achievement. In a broad sense, academic achievements are a series of educational results that are generally considered valuable, including but not limited to communication (speaking, reading, writing), calculation, literacy, and thinking abilities that enable students to achieve success in school and society (Lindholm-Leary and Borsato, 2006; Steinmayr et al. 2014). However, to better evaluate and describe academic achievements, most researchers adopt a narrow definition limited to standardized achievement test scores. Grades, often in the form of a grade point average (GPA), create a succinct way of expressing academic achievement levels in a common currency (Liou et al. 2021). Although some educators have philosophically opposed the practice of grading, seeing it as extreme reductionism, grades are still a relatively fair and holistic expression of academic achievement in the international community (Resh, 2010; Yatczak et al. 2021). To accurately assess whether the student's academic achievement has accomplished the learning objective, this study used grades, including examination scores, GPA, quiz outcomes, etc., as a measure of academic achievement.

Under the current education system, academic achievement is an important indicator for measuring students' learning, determining whether students can continue their studies, and judging the quality of education (York et al. 2015). Numerous

research results show that individual differences have an important impact on a student's academic achievement, and different factors such as demographics, intelligence, behavioral characteristics, thinking ability, and psychological factors (attitude, self-esteem, self-efficacy, self-concept, etc.) have been used as research variables to explain academic achievement (Al-Zoubi and Younes, 2015; Wolff et al. 2021). However, as learning environments and content continue to change, new factors and issues have emerged in the research field of individual differences in academic achievement, such as DL. Therefore, there still is theoretical and practical significance in exploring the factors that lead to differences in academic achievement (Camacho-Morles et al. 2021).

The relationship between DL and students' academic achievement. As DL is widely included in school curricula (Gelen, 2017), many researchers have begun to focus on the relationship between DL and academic achievement (Pala and Basibuyuk, 2020). Yang and Kim (2014) conducted a questionnaire survey among 321 university students. The results showed that the DL of students in online learning positively affected their academic achievement. Martinez-Abad et al. (2016) evaluated the digital skills of 258 Spanish middle school students through a questionnaire survey. The results also showed that digital skills were significantly positively correlated with academic achievement. Hurwitz and Schmitt (2020) conducted a longitudinal study on Internet use, DL, and academic achievements of children in 101 American families to explore whether the Internet use and DL of students in early childhood (average of 5.24 years old) would benefit their academic achievements in middle childhood (average of 11.28 years old). The results indicated that there was a significant positive correlation between children's DL and school performance.

However, some studies have reached the opposite conclusion. Abbas et al. (2019) conducted a questionnaire survey and semi-structured interview on a randomly selected sample of 800 college students to explore the impact of DL on the academic performance of adult learners. They reported that DL significantly impacts students' communication skills, research skills, and confidence but has little effect on students' cumulative grade point average (CGPA). Darlis and Sari (2021) collected data including the student characteristics, DL, and performance of 43 college students in an introductory management course, then analyzed the data using a logistic regression model. Research results indicated that in blended learning, student characteristics and DL had no significant impact on student achievement.

In summary, whether there is a positive correlation between DL and academic achievement is still controversial, as the conclusions of various studies differ. In addition, these existing studies have explored the relationship between DL and students' academic achievement, but there is a lack of comprehensive research on how different influencing factors (such as grade, subject, etc.) affect this relationship. This study will further carry out a moderator analysis based on the results of the meta-analysis and explain how different moderator variables affect the relationship between DL and academic achievement.

Moderator variables. Based on the results of the literature review, we identified five moderating variables: grade level, orientations of DL, subject, sampling method, and gender, and we focused on their moderating effects on the relationship between DL and academic achievement.

Grade level. Grade level is an unavoidable factor in the cultivation of DL and academic achievement. Hurwitz and Schmitt (2020) discovered that when young people have more access to information resources, their DL is stronger, and their academic achievement is better. Li and Ranieri (2010) found that factors such as age seem to have an impact on students' performance. In addition, some researchers have conducted empirical studies to explore the effect of grade level. For example, Tang and Chaw (2016) noted a moderate correlation ($r = 0.35$) between college students' DL and their academic outcomes. Pagani et al.'s (2016) study showed that the DL of secondary school students was highly correlated ($r = 0.546$) with their academic achievement. Judge (2005) concluded that there was a moderate correlation ($r = 0.21$) between kindergarten students' DL and academic achievement. Hence, we speculated that the correlation between DL and academic achievement is different in different grade levels and looked to further verify this through meta-analysis.

Orientation of digital literacy. When we searched for literature with the keyword "Digital Literacy", it appeared with expressions such as Digital Competence, Digital Skill, ICT Literacy, Internet Literacy, and Computer Technology. To classify these terms, we referred to Martínez-Bravo et al. (2020) and Brown (2018) and categorized their work into two orientations: "Technological Skills" and "Comprehensive Literacy." Technological Skills refer to the different competencies (technique operation, communication, information processing, collaboration) used to solve problems using digital technology. On the other hand, Comprehensive Literacy is more integrated and focuses on the pedagogical area of DL—for example, the integration of technical, cognitive, and social-emotional dimensions (Eshet, 2012; Ng, 2012). By comparing different studies, we found that the correlation value of "Technological Skill" and academic achievement ($r = 0.153$) (Shao and Purpur, 2016) is lower than that of "Comprehensive Literacy" and academic achievement ($r = 0.449$) (Yuki, 2021). This directed our attention to the influence of the orientations of DL on the relationship between DL and academic achievement.

Subject. Some literature studied the relationship between students' DL and their academic achievement in different subjects. Barlow-Jones and van der Westhuizen's (2011) study reported a medium correlation ($r = 0.387$) between DL and academic achievement in computer science. In Pagani et al.'s (2016) study, there was a high correlation between students' DL and academic achievement in mathematics ($r = 0.546$) and a medium correlation between students' DL and academic achievement in language subjects ($r = 0.368$). These findings led us to realize that, although every subject can benefit from the use of information technology today, different subjects benefit differently from the use of information technology. Therefore, we speculated whether the relationship between students' DL and academic achievement varies by subject. Thus, we considered the subject as a factor that may mediate the relationship between DL and academic achievement.

Sampling method. We noticed that the sampling methodologies used in the collected literature predominantly fall into two categories: convenience sampling and random sampling. Convenience sampling involves selecting subjects that are proximal to the researcher and capable of participating in the study. In contrast, random sampling is a more precise technique for acquiring random samples, ensuring that the selected samples are representative of the population and are chosen impartially. Tadesse et al. (2018) used convenience sampling to select 536 students and found that students' digital literacy was highly correlated with their academic performance ($r = 0.420$). Pagani et al. (2016) used random sampling to select 2025 students and found that students' digital literacy was moderately correlated with their academic

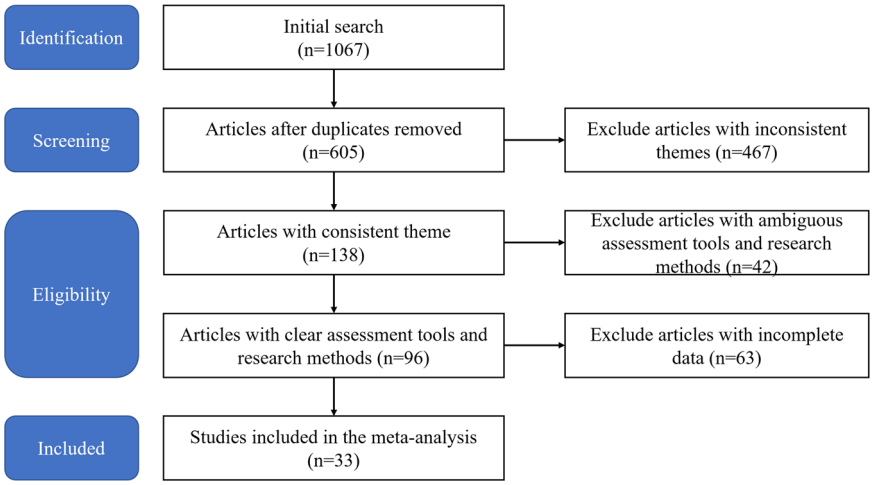

Fig. 1 The study's selection process.

performance ($r = 0.368$). However, Shao and Purpur (2016) also used convenience sampling and found that there was only a low correlation between the digital literacy of 344 students and their academic performance ($r = 0.153$). Therefore, whether the two different sampling methods affect the relationship between DL and academic performance is a question worth investigating.

Gender. Some studies support a stronger link between boys' DL and academic achievement than girls. Since boys are more active online than girls, they are more interested in technology and are more active in performance (Tsai and Tsai, 2010). Furthermore, male students are likely to take more relevant courses at school and thus have more computer knowledge and experience than female students (He and Freeman, 2010). However, some studies suggest the opposite, finding that boys pay less attention to academic learning and are more interested in playing games than immersing themselves in digital learning activity that has more potential for developing academic achievement (Lau and Yuen, 2014). There are significant differences in the DL of male and female students in middle school, with boys performing poorly and girls having more advantages such as girls are better at communication and collaboration in the digital environment (Jin et al. 2020). Therefore, we believe it is necessary to analyze the moderating effect of gender on the relationship between DL and academic achievement.

Study purpose. This study focuses on the relationship between DL and academic achievement based on experimental and quasi-experimental research in the field. The specific purposes are as follows:

(1) To examine the effect sizes of correlations between DL and students' academic achievement.

(2) To explore the influence of moderator variables on the relationship between DL and students' academic achievement.

Methods

Article selection. To identify the existing studies exploring DL's impact on students' academic achievement, we utilized different types of research resources. We searched for relevant academic papers in publisher electronic databases such as Springer, Taylor & Francis, ScienceDirect, and EBSCO, as well as comprehensive research databases like Web of Science. Following that, we also used Google Scholar, a third-party search engine, to ensure that relevant literature was collected. We used index keywords, including "digital literacy", "academic achievement", "academic performance", "students' achievement," "students' performance," and "students' success", to find all the relevant literature. Two researchers screened each paper according to the eligibility criteria to determine its appropriateness for this study. Finally, all papers that met the qualification criteria were written in English.

Eligibility criteria. We selected the primary studies based on the titles, keywords, and abstracts. Then we excluded the studies that did not fulfill the following eligibility criteria: (1) the studies explored the relationship between DL and students' academic achievement; (2) the studies reported on the assessment tools and research methods; (3) the studies explicitly reported on the Pearson product-moment correlation coefficient or t or F values that can be converted to r. Figure 1 presents the study's selection process.

Study coding. To better analyze the identified articles and explore the research purpose, we extracted data using a content analysis technique recommended by Hsu et al. (2013). We designed a data extraction form to collect the relevant information, which included: author(s) and year of publication, number of samples, proportion of male students and female students, grade levels, orientations of DL, subjects, and sampling methods. Then, we were guided through the coding process by the following criteria: (1) Effect sizes were coded for each independent sample based on one independent sample, but if a study had several independent samples, the effect sizes were coded individually; (2) If a study indicated correlations between students' DL and academic achievement across multiple subjects, we would code them separately; (3) If a study only indicated correlations between different dimensions of DL and academic achievement, the average of these correlations was calculated as the effect size; and (4) if a study indicated not only the total correlation between DL and academic achievement but also the correlation between DL and academic achievement in different dimensions, we encoded only the former. Finally, we identified 35 independent effect sizes from the 33 articles that had been selected (see Table 1).

After finishing the coding process, we calculated the effect sizes between students' DL and academic achievement in each sample according to the principles of meta-analysis (Lipsey and Wilson, 2001). Then, we tested whether the correlation between students' DL and academic achievement was moderated by the following factors: (1) grade level; (2) orientation of DL; (3) subject; (4) sampling method; or (5) gender.

Table 1 Studies Included in the Meta-Analysis.

Name(year)	Sample	*r*	Grade level[a]	Orientation of DL[b]	Subject	Sampling method[c]	Male/Female %[d]
Barlow-Jones and van der Westhuizen (2011)	171	0.363	4	1	Computer Science	1	N
Darlis and Sari (2021)	43	0.315	4	1	Social Science	1	N
Díaz and Cano (2019)	1376	0.320	3	1	Math	1	N
Falode et al. (2017)	100	−0.053	4	1	Computer Science	2	N
Flierl et al. (2018)	6874	0.324	3	1	Other	1	54/46
Gubbels et al. (2020)	5183	0.060	2	1	Language Arts	2	49.2/50.8
Hatlevik et al. (2015)	593	0.360	3	1	Other	2	N
Huffman and Huffman (2012)	384	0.080	4	2	Social Science	1	N
Hurwitz and Schmitt (2020)	101	0.440	1	2	Language Arts	1	45/55
Irvin (2007)	4048	0.230	4	1	Language Arts	1	N
Jackson et al. (2011)	482	0.100	2	2	Other	1	47.1/52.9
Judge (2005)	1601	0.210	1	2	Math	2	51.6/48.4
Judson (2010)[a]	5958	0.076	1	2	Language Arts	1	N
Judson (2010)[b]	5089	0.062	2	2	Language Arts	1	N
Kim (2019)	916	0.320	4	1	Computer Science	1	38.2/61.8
Lee (2015)	90	0.253	2	1	Language Arts	1	40/60
Leung and Lee (2012a)	718	0.052	1	2	Other	2	44.4/55.6
Martens and Hobbs (2015)	400	0.190	3	2	Social Science	1	N
Martinez-Abad et al. (2016a)	285	0.300	3	2	Language Arts	1	54.7/45.3
Martinez-Abad et al. (2016b)	285	0.220	3	2	Math	1	54.7/45.3
Mehrvarz et al. (2021)	319	0.347	4	1	Other	1	56.7/43.3
Pagani et al. (2016)	2025	0.368	3	2	Language Arts	**2**	50/50
Sabir and Naureen (2017)	100	0.103	2	1	Other	2	N
Salleh et al. (2011)	549	0.232	4	1	Other	1	27.9/63.1
Santos and Ramos (2019)	808	0.273	3	1	Other	1	53.1/46.9
Shao and Purpur (2016)	344	0.153	4	2	Language Arts	1	N
Silamut and Petsangsri (2020)	40	0.477	4	1	Other	2	N
Sulisworo (2013)	72	0.059	3	2	Natural Science	2	N
Tadesse et al. (2018)	536	0.420	4	1	Language Arts	1	80/20
Tang and Chaw (2016)	161	0.328	4	1	Other	1	54/46
Tien and Fu (2008)	2719	0.344	4	1	Other	2	N
Yang and Kim (2014)	321	0.340	4	1	Social Science	1	37.4/62.6
Yu et al. (2021)	449	0.080	4	1	Natural Science	1	53/47
Yuki (2021)	33	0.449	4	1	Language Arts	1	N
Ziya et al. (2010)	4942	0.289	3	2	Math	2	N

[a]For "Grade level": 1 = primary school, 2 = middle school, 3 = high school, 4 = college;
[b]For "Orientation of DL": 1 = Comprehensive literacy, 2 = Technological literacy.
[c]For "Sampling method": 1 = Convenience sampling, 2 = Random sampling.
[d]For "Male/Female": N = not reported.

The grade level was coded as primary school (K-grade 5), middle school (grade 6–9), high school (grade 10–12), and college (university and higher vocational college). The orientation of DL was coded as Comprehensive Literacy (DL viewed as comprehensive literacy in research) and Technological Skills (DL viewed as Technological Skills in research). The subject was coded as Language Arts, Math, Computer Science, Social Science, Natural Science, and Other. Other represented comprehensive academic achievement in multiple subjects. The sampling method was coded as convenience sampling and random sampling. In addition, the proportion of Male/Female students was recorded when coding the gender.

Data analysis. In this study, we used meta-analysis software (CMA version 2.0) to perform the meta-analysis. CMA version 2.0 is a powerful meta-analysis tool that enables the statistical synthesis of results from multiple independent studies. It offers a wide range of features, including effect size calculation, confidence interval estimation, heterogeneity testing, sensitivity analysis, and publication bias assessment. Averaged weighted (within and between inverse variance weights) correlation coefficients of independent samples were used to calculate the average effect sizes. Moderators were determined based on the homogeneity test, which reflected the differences in effect sizes between samples' characteristics. If the homogeneity test results were significant, we performed a post-hoc analysis. For the adjustment of continuous variables, we examined the change of effect sizes explained by the moderators using meta-analysis in this study.

Cohen's (1988) classification was frequently used in literature. For instance, Fan and Chen (2001) adopted Cohen's classification to explore the relationship between parental involvement and students' academic achievement. Madigan (2019) used Cohen's classification to research the relationship between perfectionism and academic performance (Madigan, 2019). In this study, we used Cohen's classification to test the effect size of the correlation coefficients (Cohen, 1988). The following are the various intervals of this classification:

(1) effect size ≤ 0.10 represents a low correlation;
(2) 0.10 < effect size < 0.40 represents a medium correlation;
(3) effect size ≥ 0.4 represents a high correlation.

Table 2 Random—model of the correlation between digital literacy and academic achievement.

k	*N*	*r*	95% CI	Homogeneity test			Test of null (two-tailed)
				Q(*r*)	*p*	I^2	*Z*-value
35	48,115	0.240	[0.194,0.284]	775.177	0.000	95.614	10.060***

***$p < 0.001$.

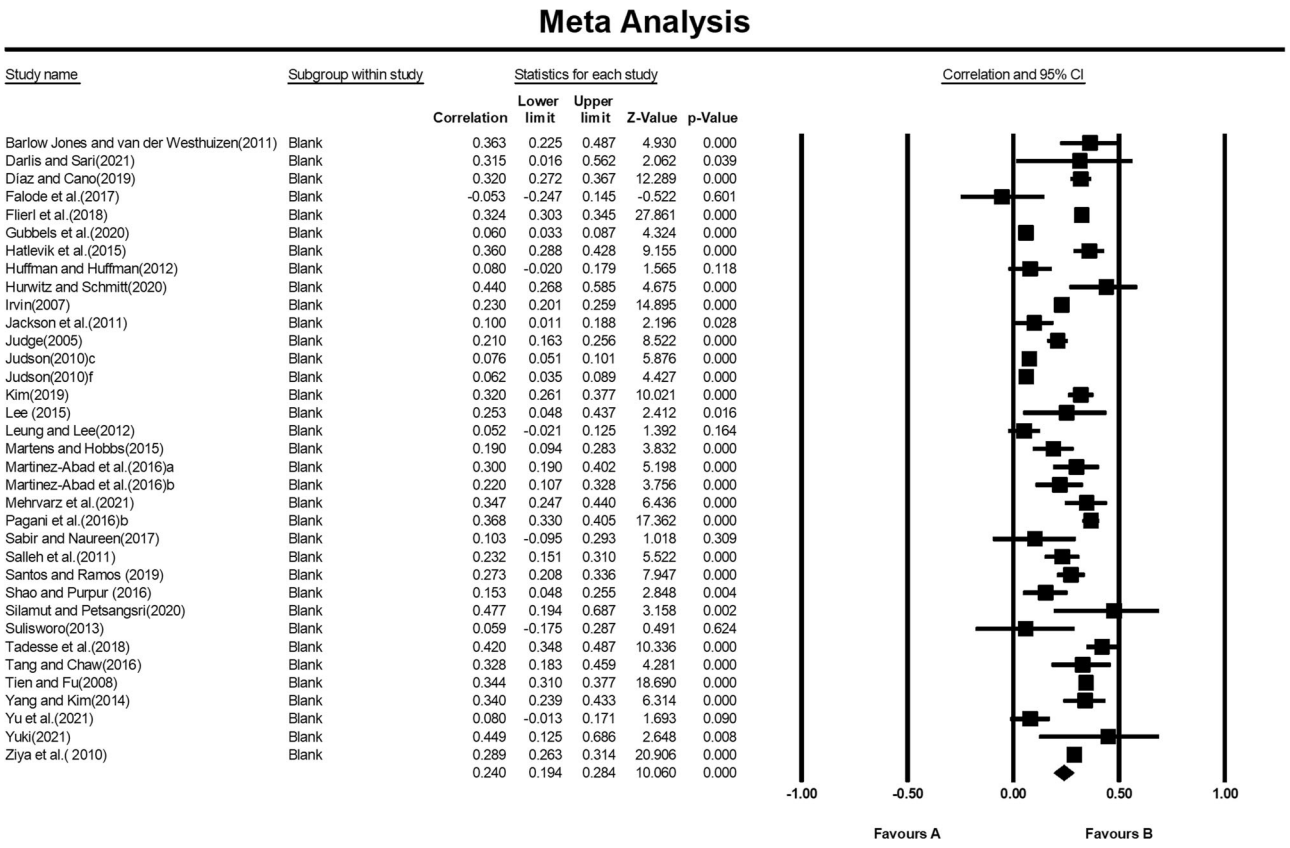

Fig. 2 The correlation between digital literacy and academic achievement.

Results

After the literature screening, a total of 35 effect sizes were obtained from 33 articles. There were 48,115 participants in the included studies, with the sample sizes ranging from 33 to 6874.

Homogeneity test. The results of the homogeneity test were statistically significant at the 95% significance level ($Q = 775.177$, $df = 34$, $p < 0.001$), suggesting heterogeneity in the data included in the study. $I^2 = 95.614\%$, which is larger than 75%, indicating a high degree of heterogeneity (Huedo-Medina et al. 2006). Therefore, the random effects model was selected to calculate the effect size. Due to the presence of heterogeneity, it was necessary to conduct a moderator analysis to explore the causes (see Table 2).

Effect size. The results of the random-effects model indicated that there was a significant medium positive correlation between DL and academic achievement ($r = 0.240$, $z = 10.060$, $p < 0.001$, $k = 35$, 95% CI = 0.194, 0.284). The forest plot (Fig. 2) depicts the effect sizes of the included studies and their confidence intervals in an intuitive way.

Moderator analysis. Moderating factor analysis was implemented to determine whether the effect size of the study was influenced by moderating variables and to find reasons for the heterogeneity. We discussed the effects of five moderating variables: grade level, orientation of DL, subject, sampling method, and gender. Tables 3 and 4 show the results.

Grade level. The results of the homogeneity test revealed a significant homogeneity coefficient between DL and academic achievement at the four grade levels (primary school, middle school, high school, and college) ($Q = 172.189$, $df = 3$, $p < 0.001$). A significant correlation was observed between DL and academic achievement in the primary school ($r = 0.166$, 95% CI = 0.062, 0.267), middle school ($r = 0.065$, 95% CI = 0.045, 0.085), high school ($r = 0.301$, 95% CI = 0.270, 0.331), and college ($r = 0.268$, 95% CI = 0.212, 0.322) groups. Results indicated that the correlation between DL and academic achievement was stronger for high school students compared to other groups, followed by college students and primary school students, while middle school students showed a lower correlation between DL and academic achievement than the other three groups.

Orientation of DL. The results obtained by the homogeneity test ($Q = 4.017$, $df = 1$, $p < 0.05$) suggested that the orientation of DL influenced the association between DL and academic achievement

Table 3 Results of Moderator Analysis.

	Between-group effect (Q_{BET})	*k*	*r* (95% CI) [LL, UL]	Homogeneity test
Grade level	$Q = 172.189^{***}$			
College		16	0.268[0.212,0.322]***	$Q = 102.503^{***}$, $I^2 = 90.665$
High school		10	0.301[0.270,0.331]***	$Q = 30.168^{***}$, $I^2 = 70.167$
Middle school		5	0.065[0.045,0.085]***	$Q = 4.171$, $I^2 = 4.091$
Primary school		4	0.166[0.062,0.267]**	$Q = 38.877^{***}$, $I^2 = 92.283$
Orientation of DL	$Q = 4.017^{*}$			
Comprehensive		21	0.278[0.221,0.333]***	$Q = 355.172^{***}$, $I^2 = 94.369$
Technological		14	0.186[0.115,0.255]***	$Q = 321.004^{***}$, $I^2 = 95.950$
Subject	$Q = 15.816^{**}$			
Computer Science		3	0.232[0.031,0.415]*	$Q = 14.033^{**}$, $I^2 = 85.748$
Language Arts		11	0.238[0.158,0.315]***	$Q = 320.748^{***}$, $I^2 = 96.882$
Math		4	0.267[0.216,0.316]***	$Q = 13.057^{***}$, $I^2 = 77.024$
Social Science		4	0.218[0.096,0.343]**	$Q = 13.656^{**}$, $I^2 = 78.031$
Natural Science		2	0.077[−0.009,0.162]	$Q = 0.027$, $I^2 = 0.000$
Other		11	0.262[0.201,0.322]***	$Q = 92.816^{***}$, $I^2 = 89.226$
Sampling method	$Q = 6.028^{*}$			
Convenience sampling		24	0.251[0.196,0.304]***	$Q = 452.625^{***}$, $I^2 = 94.919$
Random sampling		11	0.214[0.194,0.302]***	$Q = 316.524^{***}$, $I^2 = 96.841$

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Table 4 Meta-regression analyses with effect size regressed onto a percentage of male students.

Variable	Parameter	Estimate	SE	*Z*-value	95% CI for β
Male (%)					
	$\beta 0$	−0.046	0.049	−0.940	[−0.141, 0.050]
	$\beta 1$	0.568	0.095	5.976***	[0.382, 0.755]
	$Q_{mode}(1, k = 18) = 35.712$, $p < 0.001$				

***$p < 0.001$.

significantly. Table 3 illustrates that the students showed stronger correlations between DL and academic achievement in Comprehensive Literacy ($r = 0.278$, 95% CI = 0.221, 0.333) than in Technological Skills ($r = 0.186$, 95% CI = 0.115, 0.255).

Subject. As indicated in Table 3, a significant correlation was observed between DL and academic achievement in Math ($r = 0.267$, 95% CI = 0.216, 0.316), Other ($r = 0.262$, 95% CI = 0.201, 0.322), Language Arts ($r = 0.238$, 95% CI = 0.158, 0.315), Computer Science ($r = 0.232$, 95% CI = 0.031, 0.415), and Social Science ($r = 0.218$, 95% CI = 0.096, 0.343). The correlation between DL and Natural Science academic achievement ($r = 0.077$, 95% CI = −0.009, 0.162) is the lowest. Overall, the homogeneity test showed significant differences between DL and academic achievement in five subject categories (Computer Science, Language Arts, Math, Social Science, Natural Science, and Other) ($Q = 15.816$, df = 5, $p < 0.01$). This result suggests that subject factors affect the relationship between DL and academic achievement.

Sampling method. The homogeneity test results ($Q = 6.028$, df = 1, $p < 0.05$) indicated a significant impact of the sampling method on the relationship between DL and academic achievement. Table 3 reveals that students exhibited a more robust correlation between DL and academic success in convenience sampling ($r = 0.251$, 95% CI = 0.196, 0.304) compared to random sampling ($r = 0.214$, 95% CI = 0.194, 0.302).

Gender. To assess whether gender played a moderating role in the association between DL and academic achievement, a meta-regression was performed on the percentage of male participants in each sample. In Table 4, the results of the meta-regression analysis ($Q_{Mode}[1, k = 18] = 35.712$, $p < 0.001$) showed that the relationship between DL and students' academic achievement was influenced by gender. Specifically, the associated effect size between DL and academic achievement was much larger in the male sample ($r = 0.522 = 0.568–0.046$) than in the female sample ($r = –0.046$).

Publication bias. Publication bias analysis is used to assess errors and biases arising from the 33 studies. In this study, two types of analysis, funnel plots, and fail-safe numbers were used to evaluate whether the results were affected by publication bias. Firstly, by observing the funnel plot (see Fig. 3), it is found that the 35 independent effect sizes included in this study were symmetrically distributed on both sides of the average effect size, and most of the studies fall in or around the funnel. Therefore, we can assume that the probability of publication bias is low.

The fail-safe number is a method to assess publication bias by calculating how many unpublished studies can be added before the results are reversed when the meta-analysis is statistically significant. When the fail-safe number is less than $5k + 10$, it shows a high possibility of publication bias. The original number of studies included in the meta-analysis is indicated by k (Rothstein and Bushman, 2015). The fail-safe number of this meta-analysis was 4774, which is much larger than 185, that is, the result obtained according to formula $5k + 10$, which also indicates that there is little possibility of publication bias in this study.

Discussion

This study explored the connection between students' DL and academic achievement and examined whether grade, orientation of DL, subject, sampling method, and gender moderated the correlation.

The connection between DL and academic achievement. We found a medium positive correlation between students' DL and academic achievement. This result showed that good DL can promote students' learning achievement, which is consistent with the view of previous studies (Buckingham, 2015; Lee, 2014; Polizzi, 2020). It is necessary to strengthen the cultivation of students' DL,

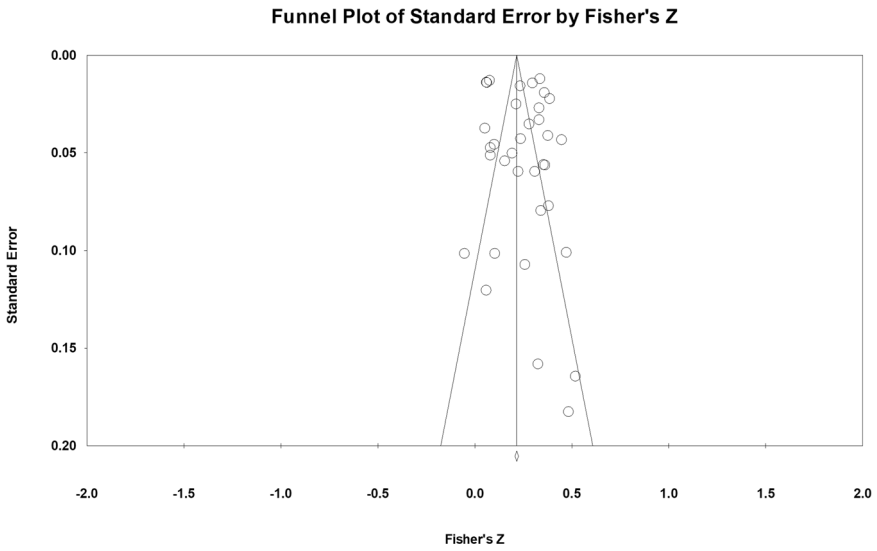

Fig. 3 The effect sizes of the correlation between digital literacy and academic achievement.

which can help improve students' academic achievement and help them adapt better to the developmental trend of today's information society. Therefore, we suggest that schools should develop students' DL and improve their ability to solve learning problems with digital technology from an early age. For example, schools in England developed students' DL through a computing curriculum starting at age 5 (GOV.UK., 2014), and Australian schools implemented DL education in a digital technology course from the foundation year (ACARA, 2022). In addition, schools should strengthen the construction of a digital learning environment, integrate digital technology into subject teaching and learning, and encourage students to adopt appropriate digital technology to study as well as improve their academic achievements. For instance, the ISTE pointed out teachers should use technology to create learning experiences to satisfy the category of independent learning in the ISTE Educator standards (ISTE, 2018).

Moderating effects. This study also found that grade level, orientation of DL, subject, sampling method, and gender moderate the relationship between students' DL and academic achievement.

The correlation between DL and academic achievement differed significantly across grades. The correlation between DL and academic achievement is low for middle school students, while the correlation between DL and academic achievement is moderate for college students, high school students, and primary school students. The low correlation between DL and academic achievement for middle school students may be due to Internet addiction. At this grade level, students want to pursue pleasure, variety, and stimulation on the Internet, and they can easily lose control of their time online (Leung and Lee, 2012b). As there is a medium correlation between DL and academic achievement for primary school students, they may benefit from teachers' and parents' guidance. Because students of this grade level have a lower technical operation ability, they use digital devices to learn more under the guidance of parents and teachers, which also promotes the improvement of students' digital literacy and academic achievements. (Kim and Jung 2022; Sefton-Green et al. 2016). At the high school and college levels, students' self-regulation ability and digital technology operation skills have been developed, which also supports them in using digital skills to improve their academic achievements (Li et al. 2021; Kaeophanuek et al. 2018). Therefore, at primary school and middle school levels, teachers and parents should give more guidance to students on the usage of digital tools, improve students' digital operational skills, and increase students' awareness of the advantages and disadvantages of digital technology being used for learning (Dashtestani and Hojatpanah, 2022).

There were significant differences in the correlation between the orientations of DL in terms of DL and academic achievement. There is a greater correlation between comprehensive literacy and academic achievement than that of technological skills. By analyzing these articles, we found that researchers had different understandings of DL at different times. In the past 6–7 years, most articles regarded digital literacy as comprehensive literacy, emphasizing not only the application of digital skills but also the development of critical thinking and innovative thinking in the process of using digital tools (Silamut and Petsangsri, 2020; Yu et al. 2021). In contrast, in articles from more than 7 years ago, digital literacy was composed of multiple technological abilities, focusing on how to apply digital tools to process information (Barlow-Jones and van der Westhuizen, 2011; Leung and Lee, 2012a). Although there is no unified definition of digital literacy at present, the meta-analysis result proves DL as a comprehensive literacy is more conducive to the joint improvement of students' DL and academic achievement. Therefore, with more and more digital tools being applied to education, DL education in schools should not be limited to the education of digital operation skills, but should also strengthen students' ability to solve problems with digital technology and improve their self-regulation in the application of digital technology (Alakrash and Abdul Razak, 2021; Kayaduman et al. 2023; Mukhlibaev, 2024; Nuryadi and Widiatmaka, 2023).

The meta-analysis showed there were significant differences in the link between academic achievement in different subjects and DL. In these subjects, there was a medium positive correlation between DL and academic achievement, except for Natural Science. The reason for the low correlation between digital literacy and academic achievement in Natural Science may be that, as Sulisworo (2013) found, students rarely participate in learning activities based on digital technology during the learning process in Natural Science, and teachers do not encourage students to use digital technology outside class to enhance their understanding of Natural Science. On the whole, the results indicated that DL could influence academic achievement in most subjects and confirmed that DL plays a key role in most aspects of learning in a digital environment (Gómez-Galán et al. 2021).

In addition, it should also be recognized that DL and academic achievement were not highly correlated. Therefore, to improve

the effectiveness of digital technology on students' subject learning, especially for Natural Science, we suggest that students not only have general DL skills but also further master the special methods and learning models of digital technology applied to different subjects. Some examples include applying virtual reality (VR) technology to explore biological science (Weng et al. 2016; Zhou et al. 2020) and adapting 3-D technology to learn engineering (Hew and Cheung, 2010; Schelly et al. 2015). We also suggest that the education department support the integration of digital technology with curriculum design and provide a rich variety of digital learning resources.

Two different sampling methods significantly affected the correlation between digital literacy and academic performance. The correlation between digital literacy and academic performance in studies using convenience sampling was higher than that in studies using random sampling. Through analyzing these articles, we believe that the main reason for this result may be attributed to the inherent characteristics of the sampling method itself and the resulting differences in sample structure. Convenience sampling is often limited to specific regions or groups (Obilor, 2023; Penn et al. 2023), which may have common characteristics such as higher education levels or broader exposure to digital technology (Flierl et al. 2018; Hurwitz and Schmitt, 2020; Mehrvarz et al. 2021), thus strengthening the relationship between digital literacy and academic performance. Random sampling encompasses a broader and more diverse population, including individuals with varying educational levels and economic backgrounds (Gubbels et al. 2020; Leung and Lee, 2012a, 2012b; Sabir and Naureen, 2017), which may dilute the correlation between digital literacy and academic performance. In general, convenience sampling may overestimate the relationship between digital literacy and academic performance due to its non-random nature and limitations in sample selection. In contrast, random sampling provides a more accurate and conservative estimate of the correlation due to its high representativeness and low bias.

Gender moderated the relationship between DL and academic achievement. Males have a stronger link than females. This result is consistent with some former studies (Hanham et al., 2021; Tsai and Tsai, 2010), but it is inconsistent with the result of Jin et al. (2020). We inferred that this is because the data from the Jin et al. (2020) study only includes middle school, while this study includes primary school through college. In addition, there are only 18 samples that provided the gender ratios of participants, which may affect the result of moderator analysis on gender. Thus, future research needs to verify the relationship between DL and achievement in different genders.

This study used a meta-analysis to explore the relationship between DL and academic achievement. The results showed significant medium-positive correlations ($r = 0.240$) between DL and academic achievement. In addition, there were significant differences in correlation between DL and academic achievement among students of different grade levels, orientations of DL, subjects, sampling methods, and genders. Therefore, we suggest that (1) schools should develop students' DL, strengthen the construction of a digital learning environment, and integrate digital technology into teaching and learning; (2) teachers and parents should give primary and middle school students more guidance on how to use digital tools, increasing their awareness of the good and bad effects of digital technology in learning; (3) DL education in schools should not be limited to the education of digital operation skills but should also strengthen students' ability to solve problems with digital technology and improve their self-regulation in the application of digital technology; and (4) students should have general digital operation skills and further master the special methods and learning models of digital technology applied to different subjects. Additionally, it is suggested that related experimental research should place greater emphasis on the random sampling method and increase the number of student participants.

Limitations and future research

The current meta-analysis was performed using strict criteria and procedures. However, it has several limitations. First, only five moderating variables (grade, orientation of DL, subject, sampling methods, and gender) were selected for analysis and discussion. Other variables, such as teaching styles, may also affect the relationship between DL and students' academic performance. Therefore, future research should consider other moderating variables to comprehensively understand and summarize the relationship between DL and students' academic achievement. Second, the studies selected only included articles in English, which may have narrowed the scope of the study and led to the neglect of certain cultures. Articles in other languages (e.g., Chinese, Korean, French, etc.) need to be analyzed in future research.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Received: 10 March 2024; Accepted: 14 January 2025;
Published online: 30 January 2025

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Feng Li: conceptualization, methodology, investigation, writing—original draft, supervision, funding acquisition. Liang Cheng, Xi Wang, Lingxia Shen, and Yuxin Ma: data collection and analysis, writing—original draft preparation. A.Y.M. Atiquil Islam: investigation, writing—reviewing and editing. This research was supported by the People's Education Press Key Project Foundation for 2023 under the 14th Five-Year Plan (2023GHB02).

Competing interests

The authors declare no competing interests.

Ethical approval

Ethical approval was not required as the study did not involve human participants.

Informed consent

Informed consent was not required as the study did not involve human participants.

Additional information

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