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A Meta-Analysis of the Effect of Interactive Technologies on Language Education

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ABSTRACT

With the enhancement of internet medium and development of science and technology, interactive technologies have gradually emerged in the field of language education. However, previous empirical studies and meta-analyses have focused on the impact of specific types of technologies. Therefore, this study aims to comprehensively synthesize the effect of overall interactive technologies on language education through meta-analysis. The results revealed that interactive technologies could exert a substantial influence on learning attitudes, self-efficacy, listening, reading, writing skills, vocabulary and grammar level, and overall learning outcomes. Additionally, numerous types of interactive technologies have demonstrated potential in language education, such as mobile apps, multimedia, technology-assisted tools, etc. In future research, educators should judiciously apply interactive technologies to different language educational processes according to their unique features, and researchers should expand their survey scope to ensure data validity.

KEYWORDS

Interactive Technologies, Language Education, Language Skills, Learning Outcomes, Meta-Analysis

INTRODUCTION

Definition of Interactive Technologies

Interactive technologies, via internet connection, establish digital interaction spaces. They excel at real-time user input and environmental sensing, vital for knowledge creation and engagement. Pifarré (2019) and Craft (2000) emphasized their role in bridging tech-human gaps. Interactive techs transformed learning environments, as per Säljö (1999). In language education, they offer authentic practice. They create simulated environments for learners to converse and collaborate, promoting fluency, accuracy, and cultural understanding. Educational research increasingly uses these techs to assess learner engagement with digital content and its impact on learning outcomes. Mercer et al.

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(2017) found that interactive techs enhanced language learning and creative dialogue in classrooms, fostering collaboration.

Backgrounds of Interactive Technologies Used in Language Education

Interactive technology-assisted education, compared to traditional face-to-face teaching in classrooms, can not only improve the efficiency of language learning but also enhance students' absorption and classroom participation (Means et al., 2009). With the continuous updates of information and communication technologies (ICTs), educators are gradually applying interactive technologies to improve language education, including online learning management systems (LMSs), online courses, more advanced applications of virtual reality, and augmented reality technologies (Zhou, 2023).

For interactive technologies, previous researchers have already demonstrated their positive impact on language education through various empirical studies. Interactive technologies could enhance language learners' learning attitudes (Karimova et al., 2023), motivation (Wei, 2023), self-efficacy (Dai et al., 2023), and achievements (Z. Wang, 2010). They could also improve students' listening (Mao, 2022), speaking (Dunn, 2012), reading (Shen, 2021), and writing skills (Y. Liang, 2021), as well as vocabulary (Rahimi et al., 2021) and grammar levels (R. Wang, 2022). Switching to another perspective, we could discover that different types of interactive technologies might exert a profound impact on language learning, such as flipped classroom models (C. Chen, 2015), games (Yan, 2019), and mobile applications (Tavassoli & Beyranvand, 2023). Though addressing positive potentials, the above studies cannot show us well-rounded results because they only focused on a specific aspect of language education or interactive technologies, thus we strongly need comprehensive meta-analysis tests to synthesize all the results.

However, the previous meta-analyses were also conducted considering the effect of certain types of interactive technologies on language education. The results of the meta-analysis by Means et al. (2009) indicated that individuals acquired better language skills under learning conditions based on online learning technologies. B. Chen et al. (2022) demonstrated through meta-analysis that language learners could achieve higher academic achievements and spark passion for language learning through immersive learning in interesting virtual spaces. On the contrary, based on Xie et al. (2021), some researchers believed that XR technology (an umbrella term encapsulating AR and VR) only had a significant impact on English language education and could not be applied to all languages. Additionally, rapidly introducing emerging technologies into language education often fails to achieve the goal of improving learning effectiveness, but instead could lead to a series of problems such as technological instability, safety risks, and physical discomfort for learners (J. Chen et al., 2022).

As a result, due to inconsistent meta-analysis results and the fact that many of them only focused on certain types of interactive technologies, it seems necessary to integrate interactive technologies to analyze their impact on language education. Therefore, by using meta-analysis testing, our study is dedicated to collecting, coding, and synthesizing previous studies and is designed to provide comprehensive and extensive quantitative research about interactive technologies in the field of language education.

Therefore, through the meta-analysis, this study aimed to answer these questions:

1. Do interactive technologies exert a great influence on language learners' learning attitudes, motivation, self-efficacy, and achievements?
2. Do interactive technologies improve learners' listening, speaking, reading, and writing skills, as well as vocabulary and grammar levels?
3. Do all types of interactive technologies, including flipped classroom models, games, mobile applications, multimedia, videos, interactive approaches, technology-assisted tools, and voice-assisted technologies, have positive impacts on language education?

LITERATURE REVIEW

Theoretical Framework

In language education, interactive technologies offer a multimodal, immersive, and collaborative learning environment. These technologies continuously explore and integrate diverse modes of communication (such as images, sounds, and videos), enhancing the efficiency of language learning (Kress, 2003; Xiao & R. Wang, 2022). By immersing learners in an environment where they can engage with knowledge using multiple senses, embodied learning is promoted (Katz, 2013). Simulations provided by these technologies facilitate effective collaboration, allowing learners to enhance their cognitive abilities while interacting with peers (Sun, 2022). The impact of these technologies on language education is significant, affecting learners' attitudes, motivation, self-efficacy, and achievements. This influence extends to all language skills—listening, speaking, reading, writing—as well as vocabulary and grammar levels. The range of interactive technologies includes flipped classroom models, games, mobile applications, multimedia, videos, interactive approaches, technology-assisted tools, and voice-assisted technologies. Many researchers believe that interactive technologies have enormous development potential in the field of assisted education in the future, especially in diversified education (Min, 2018), children's language learning, and creating a learning atmosphere (Sophie et al., 2023).

Learning Attitudes, Motivation, Self-Efficacy, and Achievements

Learning attitudes, motivation, self-efficacy, and achievements are key factors in language learning. Learning attitudes refer to students' sentiments and beliefs toward the process of language learning (Jarinee & Wipanee, 2018). Motivation is the driving force that encourages students to study effectively, whether intrinsic or extrinsic (Jarinee & Wipanee, 2018). Self-efficacy is individuals' belief in their ability to perform specific behaviors required for achieving desired outcomes (Bandura, 1977). Achievements measure the extent of academic growth over a given period (Yan, 2019).

Researchers have delved into the impact of interactive technologies on these factors. Some studies found that students in computer-aided teaching (CAT) or game-based classrooms exhibited more positive attitudes toward language learning compared to those using traditional methods (Karimova et al., 2023; Kocaman et al., 2016; Yükseltürk et al., 2018). However, regarding motivation, no significant difference was observed between the control group and learners aided by e-books (Adel, 2023). The research by Qiu (2017) supported the efficacy of mobile internet environments in cultivating self-efficacy in language learning. Similarly, technical-based pedagogical design also had a significant effect on enhancing students' language learning self-efficacy (Joldanova et al., 2022). Additionally, artificial intelligence (AI)-assisted teaching has been shown to significantly enhance second language (L2) achievements among students (Wei, 2023). Considering these findings, we propose the following null hypotheses:

- H1. Interactive technologies could not significantly improve attitudes at the *.05* level in language education.
- H2. Interactive technologies could not significantly enhance learning motivation at the *.05* level in language education.
- H3. Interactive technologies could not significantly improve self-efficacy at the *.05* level in language education.
- H4. Interactive technologies could not significantly improve learning achievements at the *.05* level in language education.

Listening, Speaking, Reading, and Writing Skills

Language skills encompass the abilities to listen, speak, read, and write. Listening skills involve the ability to comprehend and identify words, as well as understand their meanings, tones, and contexts (Ali, 2022). Speaking skills are defined as the ability to communicate fluently and effectively using a specific language (Ali, 2022). Reading skills reflect individuals' knowledge and understanding of language, representing their critical thinking ability to process, analyze, and synthesize written information (Ali, 2022). Writing skills enable language learners to express their thoughts and ideas creatively in a structured and organized manner (Ali, 2022).

Researchers have examined the performance of these four language skills in the context of interactive technology-assisted education. Kılıç (2020) and Min (2018) found that students' listening scores improved with the assistance of Education Informatics Network (EIN) listening materials and multimodal teaching techniques, leading to increased enthusiasm for learning. Dunn (2012) proposed that asynchronous voice-conferencing technology could effectively enhance language learners' fluency through diverse courses. Similarly, Bashori et al. (2020) noted that web-based education helped improve learners' speaking skills and reduce learning anxiety. Khadragy (2016) and Sun (2009) believed that online-assisted classrooms were beneficial for language learners' reading abilities, including text recognition and information extraction. However, Glymph (2012) argued that with the assistance of blogs, students did not make progress in vocabulary usage, comprehensibility, and language control in written texts. Based on these findings, we propose the following null hypotheses:

H5. Interactive technologies could not significantly improve listening skills at the *.05* level in language education.
H6. Interactive technologies could not significantly improve speaking skills at the *.05* level in language education.
H7. Interactive technologies could not significantly improve reading skills at the *.05* level in language education.
H8. Interactive technologies could not significantly improve writing skills at the *.05* level in language education.

Vocabulary and Grammar Levels

The importance of vocabulary in language learning cannot be overstated. It serves as the basis for effective communication and is often used as a measure of learners' proficiency at different levels, including their understanding of academic terms (Ha, 2022). Instagram, for instance, has been identified as a valuable tool for enhancing technical vocabulary knowledge among EAP university students (Tavassoli & Beyranvand, 2023). Digital game-based tasks could also assist learners in acquiring more word knowledge (Rasti-Behbahani & Shahbazi, 2022). Additionally, mobile-based learning tools, as demonstrated by Zakian et al. (2022), could significantly enhance learners' retention of vocabulary meanings over extended periods.

The grammar component of language learning is equally crucial. It not only aids in effective communication but also reflects learners' ability to structure coherent thoughts into sentences (Lopez Vera, 2022). With the assistance of modern technologies, students have been observed to significantly improve their grammar skills, particularly in their ability to choose appropriate tenses and transition between active and passive sentence structures (Karimova et al., 2023; Shen, 2021; R. Wang, 2022). In light of these findings, we propose the following null hypotheses:

H9. Interactive technologies could not significantly improve vocabulary levels at the *.05* level in language education.
H10. Interactive technologies could not significantly improve grammar levels at the *.05* level in language education.

H11. Interactive technologies could not significantly improve overall learning outcomes at the *.05* level in language education.

Flipped Classroom Models, Games, and Interactive Approaches

In this study, flipped classroom models are described as models that allow students to learn language in advance through video lectures, both in and out of the classroom, thereby freeing up time for more student-centered collaborative learning (Bergmann & Sams, 2013). Gamified education, on the other hand, involves the use of human-computer interactive intelligent devices and gamification mechanisms to obtain real-time teaching data for students in language learning (Shen, 2021). Interactive approaches refer to those that integrate diverse socio-academic interaction finders and practice communities, establishing online environments with the support of electronic models to promote communication among language learners (Idrees, 2017).

Numerous studies have been conducted to investigate the impact of these technologies on language education. The implementation of flipped classroom models in foreign language education has been found to significantly enhance students' learning competence and self-worth, making the models gradually popular in schools (Sun, 2022; C. Chen, 2015). After adopting the game-based student response systems (GBSRS), no significant differences were observed in language learners' self-efficacy and performances (Sarabchian, 2021). On the contrary, Q. Zhang (2022) discovered that interactive courses based on virtual reality have boosted the improvement of language learners' self-efficacy and achievements. Though Cloe (2012) also suggested that interactive electronic readers could serve as sufficient language learning resources that provide students with immersive additional input, she did not observe significant improvements in the experimental group's achievements in post-evaluation. Therefore, we propose the following null hypotheses:

H12. Flipped classrooms in interactive technologies could not have a significant impact on language education at the *.05* level.
H13. Games in interactive technologies could not have a significant impact on language education at the *.05* level.
H14. Interactive approaches in interactive technologies could not have a significant impact on language education at the *.05* level.

Mobile, Multimedia, and Technology-Assisted Tools

Mobile-assisted learning has emphasized the potential of developing applications and platforms on portable devices to provide affordances and opportunities for flexible language learning (McQuiggan et al., 2015). Multimedia, also known as multimodal teaching in education, utilizes various means such as sounds, images, and role-playing to engage learners' diverse senses and enable them to participate in language learning collaboratively (Min, 2018). Technology-assisted tools are computer-based resources that provide language learners with platforms and extensive collections of authentic instructional materials via the internet (Lopez Vera, 2022).

To synthesize the research on the role of these interactive technologies in language education, we reviewed studies on mobile podcasting's positive impact on learners' listening abilities (Woloshen, 2012), mobile e-learning applications' short-term effects on seventh-grade language learners' scores (Bu, 2023), features of mobile touchscreen apps (such as built-in narration and real-time dialogue prompts) exerting a supportive effect on language acquisition (Sophie et al., 2023), multimedia's effectiveness in stimulating students' enthusiasm for learning (Ma, 2023; Tang, 2021; Z. Wang, 2010), and technology-assisted tools' profound influence on EFL students' grades and learning motivation through the integration of interactive whiteboards and Quizlet learning software (Cho, 2021; Y. Liang, 2021). Based on these findings, we propose the following null hypotheses:

H15. Mobile in interactive technologies could not have a significant impact on language education at the *.05* level.
H16. Multimedia in interactive technologies could not have a significant impact on language education at the *.05* level.
H17. Technology-assisted tools in interactive technologies could not have a significant impact on language education at the *.05* level.

Videos and Voice-Assisted Technology

Video-assisted learning methods center on the capture and representation of dynamic visual movements to enhance audio-visual input. This approach enables language learners to focus more intently (Rahimi et al., 2021). The application of instructional videos has led to significant differences between experimental and control groups, indicating that video-assisted education can foster a deeper understanding of knowledge among language learners (Khadragy, 2016; Shi, 2012; Smith, 2012).

Voice-assisted technology, which combines acoustics, linguistics, and computer science, enables precise pronunciation of words and phrases (Mao, 2022). Text-to-speech (TTS) technology has the potential to significantly develop language learners' listening and communicative skills (Mao, 2022; J. Zhang, 2020). Nevertheless, Dunn (2012) proposed that VoiceThread may not enhance students' word base or language control skills. Based on these findings, we propose the following null hypotheses:

H18. Videos in interactive technologies could not have a significant impact on language education at the *.05* level.
H19. Voice-assisted technologies in interactive technology could not have a significant impact on language education at the *.05* level.
H20. All kinds of interactive technologies could not have a significant impact on language education at the *.05* level.

Through the review of previous empirical research on the impact of interactive technologies on language education, we can infer that many types of technologies have positive impacts on most aspects of language education, but there are still a few exceptions left. Moreover, considering the inconsistent meta-analysis results of previous studies on certain types of interactive technologies mentioned in the introduction, we cannot fully affirm the positive role of interactive technologies in language learning. Therefore, based on the proposed null hypotheses, our research needs to integrate all types of interactive technologies and conduct data analysis to examine their roles in the field of language education.

RESEARCH METHODS

To test the proposed null hypotheses, we conducted a meta-analysis. The meta-analytical review method allows us to synthesize previous research results accurately, making it suitable for this study. By analyzing Subgroups 3 & 4, this meta-analysis summarized the impact of interactive technologies, including various types, on various aspects of language education. For Subgroup 3, we coded variables such as students' learning attitudes, motivation, self-efficacy, and achievements, as well as listening, speaking, reading, writing skills, vocabulary, and grammar levels (Table 1). For Subgroup 4, we coded different kinds of technologies, including flipped classroom models, games, mobile applications, multimedia, videos, interactive approaches, technology-assisted tools, and voice-assisted technologies (Table 2).

Table 1. Subgroup 3 of Included Studies

N	Focus	Study
1	Attitude	Karimova et al. (2023), Yükseltürk et al. (2018), Kocaman & İskender (2016)
2	Motivation	Wei (2023), Adel (2023), Sun (2022), Meli (2009)
3	Self-efficacy	Dai et al. (2023), Sarabchian (2021), Yükseltürk et al. (2018), Qiu (2017),
4	Learning achievements	Wei (2023), Sarabchian (2021), Yan (2019), Wang (2010)
5	Listening skills	Mao (2022), Yang (2022), Zhang (2020), Kılıç (2020), Min (2018)
6	Speaking skills	Liang et al. (2023), Adel (2023), Jiang (2017), Chen (2015), Prefume (2015), Woloshen (2013), Dunn (2012)
7	Reading skills	Shen (2021), Khadragy, (2016), Cloe (2012), Su (2009)
8	Writing skills	Dai et al. (2023), Liang (2021), Shen (2021), Idrees (2017), Glymph (2012), Guo & Jia (2009)
9	Vocabulary	Karimova et al. (2023), Tavassoli & Beyranvand (2023), Bu (2023), Ma (2023), Zakian et al. (2022), Rahimi et al. (2021), Tang (2021), Cho (2021), Abudou (2014), Smith (2012), Shi (2012), Meli (2009)
10	Grammar	Karimova et al. (2023), Lopez Vera (2022), Wang (2022), Shen (2021)

Table 2. Subgroup 4 of Included Studies

N	Focus	Study
1	Flipped classroom	Sun (2022), Chen (2015), Prefume (2015)
2	Game	Sarabchian (2021), Shen (2021), Yan (2019), Yükseltürk et al. (2018)
3	Interactive approach	Adel (2023), Jiang (2017), Idrees (2017), Cloe (2012)
4	Mobile	Bu (2023), Tavassoli & Beyranvand (2023), Zakian et al. (2022), Qiu (2017), Abudou (2014), Woloshen (2013)
5	Multimedia	Dai et al. (2023), Karimova et al. (2023), Ma (2023), Liang et al. (2023), Tang (2021), Min (2018), Wang (2010), Guo & Jia (2009), Meli (2009), He (2008)
6	Technology-assisted tool	Wei (2023), Lopez Vera (2022), Yang (2022), Cho (2021), Liang (2021), Kılıç (2020), Kocaman & İskender (2016), Glymph (2012), Sydorenko (2011), Su (2009)
7	Video	Wang (2022), Rahimi et al. (2021), Khadragy (2016), Smith (2012), Shi (2012)
8	Voice-assisted technology	Mao (2022), Zhang (2020), Dunn (2012)

Literature Search

We conducted this meta-analysis according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). From December 5th to 23rd, we conducted a rigorous and detailed literature search from two online academic databases—Web of Science and China National Knowledge Infrastructure (CNKI) and collected a total of 117 results. We obtained 77 results by searching the topic column of Web of Science using the keywords "technology," "language education," and "control group." Additionally, we retrieved 40 results from CNKI by entering "interactive technology," "language education," and "control group" (in Chinese) or "information technology," "language education," and "control group" (in Chinese) in the topic search area. The timeframe for retrieved articles ranges from 2008 to November 6, 2023.

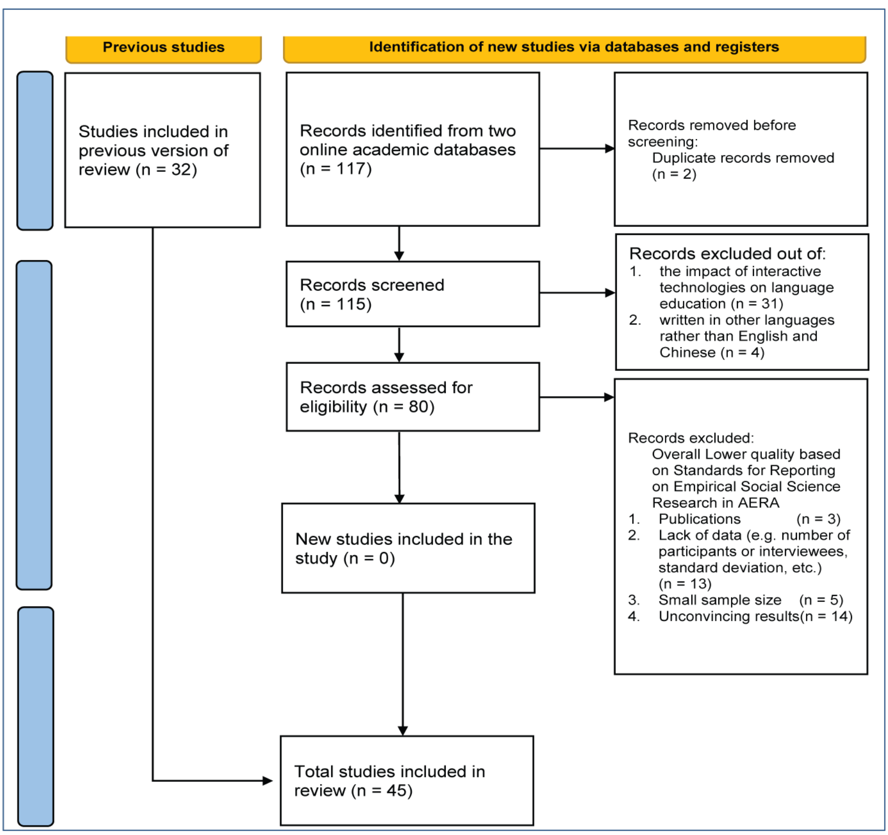
Inclusion and Exclusion Criteria

To ensure the reliability of our research, we have defined strict inclusion criteria for the literature review. First, studies must focus on the impact of interactive technologies on language education. Second, they must include both control and experimental groups for comparison. We also require reliable data and only consider English or Chinese articles to limit linguistic bias. Articles that do not meet these criteria or have small sample sizes are excluded. Articles that lack sufficient data (such as standard deviation, experimental or control groups' data, number of participants, or interviewees) also are removed. Furthermore, we compared the results of numerous articles and removed some that had unconvincing results due to incomplete experimental design, significant grade differences among participants, and a lack of clear indication of post-test results with the assistance of interactive technologies. The search process is outlined in Figure 1, using various search engines and databases. By following these criteria, we aim for rigorous, objective, and well-founded analysis.

Study Coding

Considering the number of coders and the inter-rater agreement, two researchers meticulously coded the samples and tested their eligibility. Using 1 or 0 to represent inclusion or exclusion, two raters independently screened and coded the articles, and finally imported the data into SPSS 23.0 for calculation through crosstabs. Ultimately, we selected 45 peer-reviewed journal articles based on the researchers' sample suggestions. The inter-rater reliability reached a satisfactory level (k = 0.848), indicating the consistency between the two researchers (Cohen, 1968).

Figure 1. A Flowchart of Literature Inclusion



Coding of Moderators

We coded the retrieved literature based on various moderators, including author, publication year, type of educational outcomes, and type of interactive technologies.

Author and Publication Year

We organized the authors in the retrieved literature alphabetically and recorded their publication years, which spanned from 2008 to November 2023.

Type of Educational Outcomes

To ensure the accuracy and comprehensiveness of our analysis, we have taken into account various educational outcomes, including students' learning attitudes, motivation, self-efficacy, and achievements. We have also evaluated their listening, speaking, reading, and writing skills, as well as their vocabulary and grammar levels. Our ultimate goal is to provide a comprehensive understanding of the impact of interactive technologies on language education. By considering these factors, we can gain a deeper understanding of how these technologies influence language learning and development.

Type of Interactive Technologies

On the other hand, we also considered various interactive technologies, including flipped classroom models, games, mobile applications, multimedia, videos, interactive approaches, technology-assisted tools, and voice-assisted technologies. These variables were compiled by us through various forms of interactive technology, such as smart classrooms, gamification, game-based student response systems, online intonation training, interactive e-books, digital flashcards, Instagram, podcasting, mobile applications, e-learning applications, wiki-based writing courses, digital stories and media, multimodal teaching, private classroom blogs, technology-mediated task-based language teaching, AI, computer-delivered automatized structured tasks (CASTs), interactive whiteboards, animation programs, voice-conferencing technology, and text to speech technology.

Execution and Features of Interactive Technology in Language Education

Multiple studies in the literature have aimed to integrate internet-based interactive technologies into classroom settings, aligning with the notion that these technologies can establish a platform for teacher-student interaction, ultimately enhancing effective language education (C. Chen, 2015; Qiu, 2017; Sun, 2022). Additionally, interactive technologies integrate visual, auditory, and video elements to create a virtual learning environment, enabling students to fully immerse themselves in language learning and enhance their language comprehension (Meli, 2009; Yükseltürk, 2018). Furthermore, interactive technologies make automated or computer-mediated tutor and peer feedback feasible, fostering enthusiasm for language learning (Idrees, 2017).

Statistical Analysis

To enhance the reliability and accuracy of our meta-analysis, we standardize effect sizes, conduct robustness checks, and test for heterogeneity. Using Stata 14.0, we analyze various metrics including standardized mean difference (SMD), confidence intervals, weights, *p* values, and pooled effects. We also create funnel plots for visualization. Among SMD metrics, we prefer Cohen's *d*, which divides the average difference between groups by the standard deviation of research results (Cohen, 1988; Sedgwick & Marston, 2013).

To assess the consistency of proportions across groups in a dichotomous data set, we use Cochran's Q statistic, which measures heterogeneity. We calculate I^2 to determine the degree of heterogeneity (Aslam, 2023; Yu, 2021), with levels defined by Higgins and Green (2011). Based on these metrics, we determine the appropriate meta-analysis model. Z statistical data and Egger's/Begg's tests are used to test for publication bias.

Analysis Results

In this section, we conducted publication bias tests and sensitivity analyses regarding the results of the meta-analysis to enhance their credibility and robustness.

Publication Bias

To obtain reliable and effective results, we first used Stata 14.0 to conduct a publication bias test on the results of the meta-analysis with Subgroup 3 and Subgroup 4 as the variables, which contain funnel plot, Begg's test, Egger's test, and trim-and-fill analysis.

The funnel plot is a scatter plot drawn from multiple research data during the meta-analysis process. If the funnel plot is symmetrical on both sides, it indicates that there is no publication bias; otherwise, there may be publication bias. For the result with Subgroup 3 as the variable, according to Figure 2, it is evident that the funnel plot is not left-right symmetric, indicating a publication bias in the results of this meta-analysis.

For the result of Subgroup 4 (Figure 3), the funnel plot is slightly asymmetrical, which may suggest the existence of publication bias. However, in addition to publication bias, factors such as low quality of small-scale research methodology, heterogeneity between studies, and opportunities can all lead to funnel plot asymmetry (Egger et al., 1997). Therefore, this article combines Begg's and Egger's tests to further examine publication bias.

Begg's test, derived from the visual evaluation of funnel plots, standardizes the effect size by subtracting the average weight and dividing it by the standard error and then tests whether there is a correlation between the size of the effect size and its standard error through corrected rank correlation analysis (Begg, 1994). For Subgroup 3, through Begg's test, the result indicates the existence of publication bias ($z = 3.53$ (continuity corrected), $Pr>|z| = 0.000$ (continuity corrected)). Similarly, the result of subgroup 4 also represents the publication bias ($z = 2.42$ (continuity corrected), $Pr>|z| = 0.016$ (continuity corrected)).

Figure 2. Funnel Plot With Pseudo 95% Confidence Limits for Subgroup 3

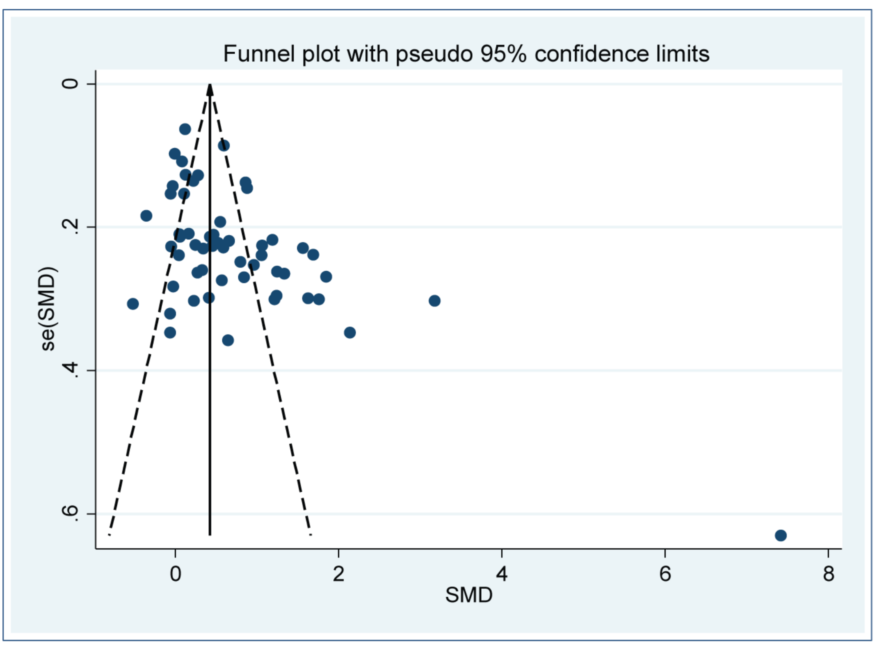
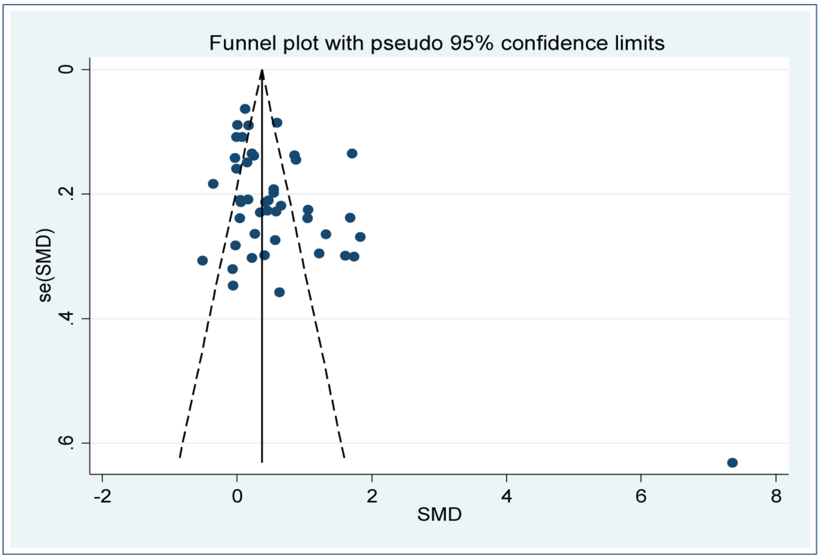
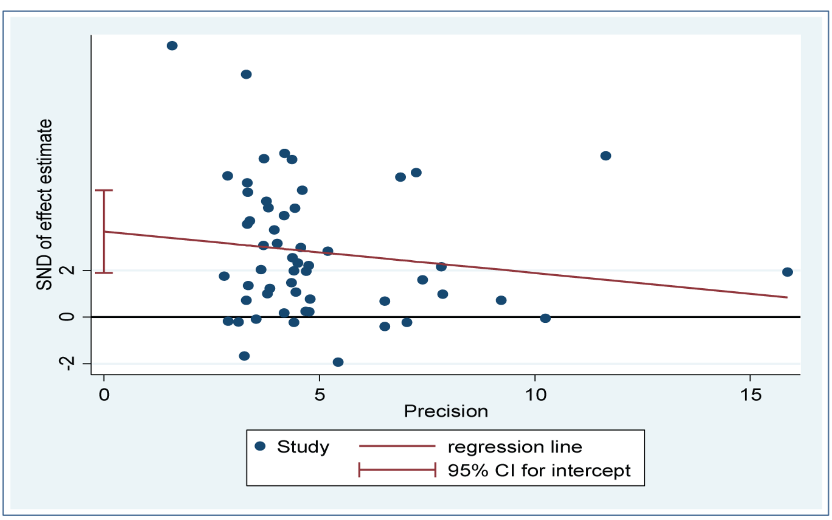


Figure 3. Funnel Plot With Pseudo 95% Confidence Limits for Subgroup 4



Similar to Begg's test, Egger's test uses linear regression to measure the symmetry of the funnel plot based on the natural logarithm of the ratio. Specifically, it uses standard normal deviation (SND) to perform regression analysis on the precision of effect estimation values. The regression equation obtained is $SND = a + b \times accuracy$. If there is asymmetry, the effects displayed in small sample experiments will systematically deviate from those in large sample experiments, and the regression line will not pass through the starting point. The intercept represents the degree of asymmetry, and the greater the deviation from 0, the more apparent the degree of asymmetry (Xu et al., 2009). For Subgroup 3, it is obvious that the regression line does not pass through the starting point, according to Figure 4. In addition, from the result of Egger's test, the intercept (Coef. = 3.673) is much greater

Figure 4. Result of Egger's Test for Subgroup 3



than 0, and the value of p is less than .05 ($p = 0.000$), which also indicates the existence of publication bias. For Subgroup 4, the value of p also represents the publication bias ($p = 0.007$).

Based on the above test results, there are publication biases in this meta-analysis with Subgroup 3, and Subgroup 4 as variables, which may be because research results with statistical significance are more likely to be published or accepted compared with those with no significant or invalid results.

To address potential publication bias and enhance the reliability of our analysis, we conducted a trim-and-fill analysis. This approach involves removing and adding studies to ensure a symmetrical distribution of studies around the average effect size, and then recalculating the true values of the effect size. For Subgroup 3, by removing 13 studies, we generated a more stable and reliable data result. After the trim-and-fill analysis correction, the estimated effect size was 3.237 using the random-effect model method, indicating that interactive technologies have a significant impact on various aspects of language education ($p < .01$). For Subgroup 4, the estimated effect from the trim-and-fill analysis was 2.399, indicating that different types of interactive technologies can influence language education ($p < .01$). Based on these findings, our previous hypotheses are supported.

Sensitivity Analysis

By using Stata 14.0, we tested the stability of the pooled effect size of the meta-analysis by removing certain individual studies (Figure 5 and Figure 6). The results reveal that if the given named study is omitted, individual studies are all located within the range between Lower CI Limit and Upper CI Limit, and they cannot affect the pooled effect size. This indicates that the results of the meta-analysis with Subgroup 3 and Subgroup 4 as variables are stable.

RESULTS

In this section, we summarize and extend our research results to test the proposed 20 null hypotheses. From the included 45 empirical literature results, we collected their experimental groups' number, mean, and standard deviation (N0, M0 & SD0), as well as the control groups' number, mean, and

Figure 5. Result of the Sensitivity Analysis for Subgroup 3 (Random, Inverse Variance)

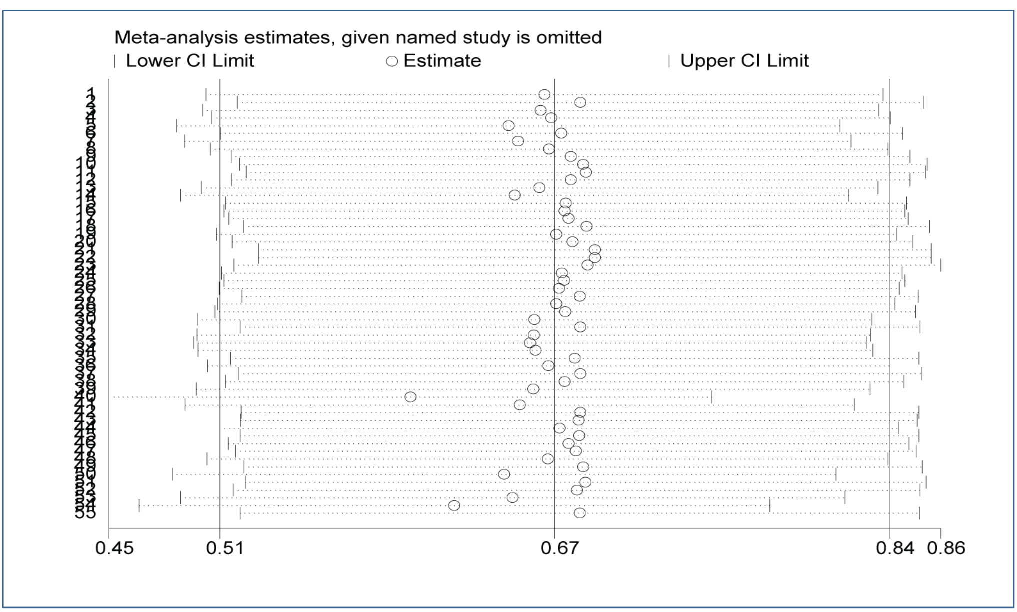
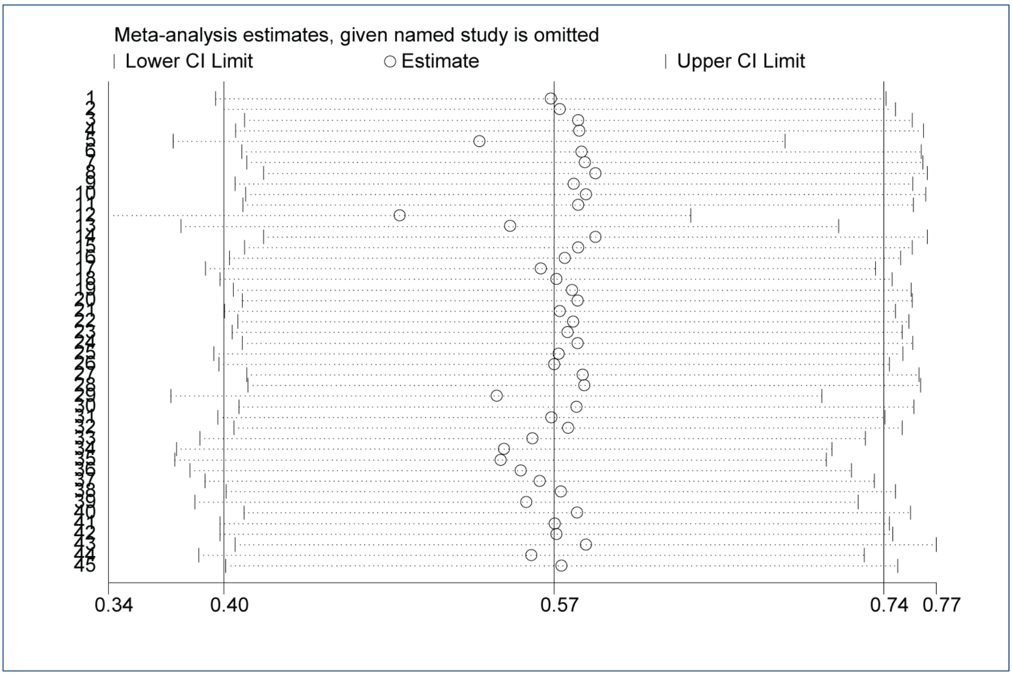


Figure 6. Result of the Sensitivity Analysis for Subgroup 4 (Random, Inverse Variance)



standard deviation (N, M & SD). The values of these control and experimental groups were all from post-test results to ensure the credibility and validity of our final meta-analysis results. Labeling the coded author name and publication year, we imported these values into Stata 14.0 with Subgroups 3 and 4 as variables for calculation. Ultimately, we synthesized the result data in Tables 3 and 4. Tables 3 and 4 show the main meta-analytic results with Subgroups 3 and 4 as variables, respectively.

H1. Interactive technologies could not significantly improve learning attitudes at the *.05* level in language education.

Given that the I^2 statistic for learning attitudes is 88.1% (Q = 16.87), there is significant heterogeneity among the effect sizes at the .05 level ($p < .01$). Therefore, we opted to use the random-effect model for our meta-analysis of learning attitudes. As summarized in Table 3, there are significant differences in attitudes between the experimental and control groups, with a significant SMD of 0.688 (95% CI [0.020, 1.356], $z = 2.02$, $p = 0.043$). This finding suggests that individuals in the interactive technology-assisted group have more positive learning attitudes compared to the control group. Consequently, we reject Hypothesis 1.

H2. Interactive technologies could not significantly enhance learning motivation at the *.05* level in language education.

Given that the I^2 statistic for learning motivation is 64.9% (Q = 8.56), there is significant heterogeneity among the effect sizes at the *.05* level ($p < .01$). Therefore, we opted to use the random-effect model for our meta-analysis of learning motivation. As summarized in Table 3, there are no significant differences in learning motivation between the experimental and control groups, with a significant SMD of 0.269 (95% CI [-0.047, 0.585], $z = 1.67$, $p = 0.096$). This finding suggests that individuals in the interactive technology-assisted group do not have more positive learning motivation compared to the control group. Consequently, we accept Hypothesis 2.

H3. Interactive technologies could not significantly improve self-efficacy at the *.05* level in language education.

Given that the I^2 statistic for self-efficacy is 86.4% (Q = 21.99), there is significant heterogeneity among the effect sizes at the *.05* level ($p < .01$). Therefore, we opted to use the random-effect model for our meta-analysis of self-efficacy. As summarized in Table 3, there are significant differences in self-efficacy between the experimental and control groups, with a significant SMD of 0.570 (95% CI [0.137, 1.003], $z = 2.58$, $p < .05$). This finding suggests that individuals in the interactive technology-assisted group have more positive self-efficacy compared to the control group. Consequently, we reject Hypothesis 3.

H4. Interactive technologies could not significantly improve learning achievements at the *.05* level in language education.

Given that the I^2 statistic for learning achievements is 66.8% (Q = 9.02), there is significant heterogeneity among the effect sizes at the *.05* level ($p < .05$). Therefore, we opted to use the random-effect model for our meta-analysis of learning achievements. As summarized in Table 3, there are no significant differences in learning achievements between the experimental and control groups, with a significant SMD of 0.216 (95% CI [-0.095, 0.527], $z = 1.36$, $p = 0.174$). This finding suggests that individuals in the interactive technology-assisted group do not have more positive learning achievements compared to the control group. Consequently, we accept Hypothesis 4.

H5. Interactive technologies could not significantly improve listening skills at the *.05* level in language education.

Given that the I^2 statistic for listening skills is 80.2% (Q = 20.19), there is significant heterogeneity among the effect sizes at the *.05* level ($p < .01$). Consequently, we employed the random-effect model for our meta-analysis of listening skills. Table 3 reveals significant differences in listening skills between the experimental and control groups, with a highly significant SMD of 0.775 (95% CI [0.285, 1.265], $z = 3.10$, $p < .01$). This finding suggests that individuals in the interactive technology-assisted group exhibit superior listening skills compared to the control group. Therefore, we reject Hypothesis 5.

H6. Interactive technologies could not significantly improve speaking skills at the *.05* level in language education.

Given that the I^2 statistic for speaking skills is 72.1% (Q = 21.50), there is significant heterogeneity among the effect sizes at the *.05* level ($p < .01$). Consequently, we employed the random-effect model for our meta-analysis of speaking skills. Table 3 reveals no significant differences in speaking skills between the experimental and control groups, with a highly significant SMD of 0.131 (95% CI [-0.138, 0.400], $z = 0.95$, $p = 0.340$). This finding suggests that individuals in the interactive technology-assisted group do not exhibit superior speaking skills compared to the control group. Therefore, we accept Hypothesis 6.

H7. Interactive technologies could not significantly improve reading skills at the *.05* level in language education.

Given that the I^2 statistic for reading skills is 86.4% (Q = 22.08), there is significant heterogeneity among the effect sizes at the *.05* level ($p < .01$). Consequently, we employed the random-effect model for our meta-analysis of reading skills. Table 3 reveals significant differences in reading skills between the experimental and control groups, with a highly significant SMD of 0.940 (95% CI [0.293, 1.587], $z = 2.85$, $p < .01$). This finding suggests that individuals in the interactive technology-assisted group exhibit superior reading skills compared to the control group. Therefore, we reject Hypothesis 7.

H8. Interactive technologies could not significantly improve writing skills at the *.05* level in language education.

Given that the I^2 statistic for writing skills is 96.6% (Q = 147.25), there is significant heterogeneity among the effect sizes at the *.05* level ($p < .01$). Consequently, we employed the random-effect model for our meta-analysis of writing skills. Table 3 reveals significant differences in writing skills between the experimental and control groups, with a highly significant SMD of 1.178 (95% CI [0.298, 2.058], $z = 2.62$, $p < .01$). This finding suggests that individuals in the interactive technology-assisted group exhibit superior writing skills compared to the control group. Therefore, we reject Hypothesis 8.

H9. Interactive technologies could not significantly improve vocabulary levels at the *.05* level in language education.

Given that the I^2 statistic for vocabulary level is 93.4% (Q = 166.77), there is significant heterogeneity among the effect sizes at the *.05* level ($p < .01$). Consequently, we employed the random-effect model for our meta-analysis of vocabulary level. Table 3 reveals significant differences in vocabulary level between the experimental and control groups, with a highly significant SMD of 0.908 (95% CI [0.350, 1.465], $z = 3.19$, $p < .01$). This finding suggests that individuals in the interactive technology-assisted group exhibit superior vocabulary level compared to the control group. Therefore, we reject Hypothesis 9.

H10. Interactive technologies could not significantly improve grammar levels at the *.05* level in language education.

Given that the I^2 statistic for grammar level is 86.0% (Q = 21.46), there is significant heterogeneity among the effect sizes at the .05 level (p < .01). Consequently, we employed the random-effect model for our meta-analysis of grammar level. Table 3 reveals significant differences in grammar levels between the experimental and control groups, with a highly significant SMD of 1.175 (95% CI [0.566, 1.784], $z = 3.78$, $p = 0.000$). This finding suggests that individuals in the interactive technology-assisted group exhibit superior grammar skills compared to the control group. Therefore, we reject Hypothesis 10.

H11. Interactive technologies could not significantly improve overall learning outcomes at the *.05* level in language education.

Given that the I^2 statistic for overall learning outcomes is 90.7% (Q = 582.90, there is significant heterogeneity among the effect sizes at the *.05* level ($p < .01$). Consequently, we employed the random-effect model for our meta-analysis of overall learning outcomes. Table 3 reveals significant differences in overall learning outcomes between the experimental and control groups, with a highly significant SMD of 0.673 (95% CI [0.509, 0.838], $z = 8.01$, $p < .01$). This finding suggests that individuals in the interactive technology-assisted group exhibit superior overall learning outcomes compared to the control group. Therefore, we reject Hypothesis 11.

Table 3. Main Meta-Analytic Results With Subgroup 3 as the Variable

N	Outcome	SMD	95% CI	Weight(%)	Heterogeneity Statistic	df	*p*	I²**	*z*	*p*
1	Attitude	0.688	0.02, 1.356	5.65	16.87	2	0.000	88.1%	2.02	0.043
2	Motivation	0.269	0.047, 0.585	7.57	8.56	3	0.036	64.9%	1.67	0.096
3	Self-efficacy	0.570	0.137, 1.003	7.72	21.99	3	0.000	86.4%	2.58	0.010
4	Learning achievement	0.216	0.095, 0.527	7.57	9.02	3	0.029	66.8%	1.36	0.174
5	Listening skills	0.775	0.285, 1.265	8.93	20.19	4	0.000	80.2%	3.10	0.002
6	Speaking skills	0.131	0.138, 0.40	12.92	21.50	6	0.001	72.1%	0.95	0.340
7	Reading skills	0.940	0.293, 1.587	7.20	22.08	3	0.000	86.4%	2.85	0.004
8	Writing skills	1.178	0.298, 2.058	10.97	147.25	5	0.000	96.6%	2.62	0.009
9	Vocabulary	0.908	0.350, 1.465	20.53	166.77	11	0.000	93.4%	3.19	0.001
10	Grammar	1.175	0.566, 1.784	7.31	21.46	3	0.000	86.0%	3.78	0.000
11	Overall	0.673	0.509, 0.838	100.00	582.90	54	0.000	90.7%	8.01	0.000

**I^2: the variation in SMD attributable to heterogeneity; between group heterogeneity not calculated; only valid with inverse variance method

H12. Flipped classroom models in interactive technologies could not have a significant impact on language education at the *.05* level.

Given that the I^2 statistic for flipped classrooms is 43.1% (Q = 3.51), there is no significant heterogeneity among the effect sizes at the *.05* level ($p = 0.173$). Consequently, we employed the fixed-effect model for our meta-analysis of flipped classrooms. Table 4 reveals significant differences in flipped classrooms between the experimental and control groups, with a highly significant SMD of 0.446 (95% CI [0.177, 0.714], $z = 3.25$, $p < .01$). This finding suggests that the effect of language education in the group that is assisted by flipped classroom is higher than in the control group. Therefore, we reject Hypothesis 12.

H13. Games in interactive technologies could not have a significant impact on language education at the *.05* level.

Given that the I^2 statistic for games is 97.6% (Q = 122.98), there is significant heterogeneity among the effect sizes at the *.05* level ($p < .01$). Consequently, we employed the random-effect model for our meta-analysis of games. Table 4 reveals no significant differences in games between the experimental and control groups, with a highly significant SMD of 0.485 (95% CI [-0.197, 1.167], $z = 1.39$, $p = 0.163$). This finding suggests that the effect of language education in the group that is assisted by games is not different from the control group. Therefore, we accept Hypothesis 13.

H14. Interactive approach in interactive technologies could not have a significant impact on language education at the *.05* level.

Given that the I^2 statistic for the interactive approach is 52.8% (Q = 6.35), there is no significant heterogeneity among the effect sizes at the *.05* level ($p = 0.096$). Consequently, we employed the fixed-effect model for our meta-analysis of the interactive approach. Table 4 reveals no significant differences in the interactive approach between the experimental and control groups, with a highly significant SMD of 0.012 (95% CI [-0.117, 0.140], $z = 0.18$, $p = 0.856$). This finding suggests that the effect of language education in the group that is assisted by an interactive approach is not different from the control group. Therefore, we accept Hypothesis 14.

H15. Mobile in interactive technologies could not have a significant impact on language education at the *.05* level.

Given that the I^2 statistic for mobile is 96.6% (Q = 148.92), there is significant heterogeneity among the effect sizes at the *.05* level ($p < .01$). Therefore, we opted to use the random-effect model for our meta-analysis of mobile. As summarized in Table 4, there are significant differences in mobile between the experimental and control groups, with a significant SMD of 1.477 (95% CI [0.341, 2.613], $z = 2.55$, $p < .05$). This finding suggests that the effect of language education in the group that is assisted by mobile is higher than in the control group. Consequently, we reject Hypothesis 15.

H16. Multimedia in interactive technologies could not have a significant impact on language education at the *.05* level.

Given that the I^2 statistic for multimedia is 55.8% (Q = 20.35), there is significant heterogeneity among the effect sizes at the *.05* level ($p < .05$). Therefore, we opted to use the random-effect model for our meta-analysis of multimedia. As summarized in Table 4, there are significant differences in multimedia between the experimental and control groups, with a significant SMD of 0.309 (95% CI [0.140, 0.478], $z = 3.59$, $p < .01$). This finding suggests that the effect of language education in the group that is assisted by multimedia is higher than in the control group. Consequently, we reject Hypothesis 16.

H17. Technology-assisted tools in interactive technologies could not have a significant impact on language education at the *.05* level.

Given that the I^2 statistic for technology-assisted tools is 91.0% (Q = 99.89), there is significant heterogeneity among the effect sizes at the *.05* level ($p < .01$). Therefore, we opted to use the random-effect model for our meta-analysis of technology-assisted tools. As summarized in Table 4, there are significant differences in technology-assisted tools between the experimental and control groups, with a significant SMD of 0.940 (95% CI [0.496, 1.385], $z = 4.15$, $p < .01$). This finding suggests that the effect of language education in the group that is assisted by technology tools is higher than in the control group. Consequently, we reject Hypothesis 17.

H18. Videos in interactive technologies could not have a significant impact on language education at the *.05* level.

Given that the I^2 statistic for videos is 54.3% (Q = 8.75), there is no significant heterogeneity among the effect sizes at the *.05* level ($p = 0.068$). Consequently, we employed the fixed-effect model for our meta-analysis of videos. Table 4 reveals significant differences in videos between the experimental and control groups, with a highly significant SMD of 0.571 (95% CI [0.339, 0.803], $z = 4.82$, $p < .01$). This finding suggests that the effect of language education in the group that is assisted by videos is higher than in the control group. Therefore, we reject Hypothesis 18.

H19. Voice-assisted technology in interactive technologies could not have a significant impact on language education at the *.05* level.

Given that the I^2 statistic for voice-assisted technology is 88.5% (Q = 17.33), there is significant heterogeneity among the effect sizes at the *.05* level ($p < .01$). Therefore, we opted to use the random-effect model for our meta-analysis of voice-assisted technology. As summarized in Table 4, there are no significant differences in voice-assisted technology between the experimental and control groups, with a significant SMD of 0.508 (95% CI [-0.043, 1.060], $z = 1.81$, $p = 0.071$). This finding suggests that the effect of language education in the group that is assisted by voice technology is not different from the control group. Consequently, we accept Hypothesis 19.

H20. All kinds of interactive technologies could not have a significant impact on language education at the *.05* level.

Given that the I^2 statistic for all kinds of interactive technology is 91.4% (Q = 512.51), there is significant heterogeneity among the effect sizes at the *.05* level ($p < .01$). Therefore, we opted to use the random-effect model for our meta-analysis of all kinds of interactive technology. As summarized in Table 5, there are significant differences in all kinds of interactive technology between the experimental and control groups, with a significant SMD of 0.567 (95% CI [0.397, 0.738], $z = 6.51$, $p < .01$).

Table 4. Main Meta-Analytic Results With Subgroup 4 as the Variable

N	Outcome	SMD	95% CI	Weight(%)	Heterogeneity Statistic	df	*p*	I²**	*z*	*p*
1	Flipped classroom	0.446	0.177-0.714	3.11	3.51	2	0.173	43.1%	3.25	0.001
2	Game	0.485	0.197-1.167	10.05	122.98	3	0.000	97.6%	1.39	0.163
3	Interactive approach	0.012	0.117-0.14	13.62	6.35	3	0.096	52.8%	0.18	0.856
4	Mobile	1.477	0.341-2.613	11.81	148.92	5	0.000	96.6%	2.55	0.011
5	Multimedia	0.309	0.140-0.478	23.01	20.35	9	0.016	55.8%	3.59	0.000
6	Technology-assisted tool	0.940	0.496-1.385	21.71	99.89	9	0.000	91.0%	4.15	0.000
7	Video	0.571	0.339-0.803	4.17	8.75	4	0.068	54.3%	4.82	0.000
8	Voice-assisted technology	0.508	0.043-1.060	7.08	17.33	2	0.000	88.5%	1.81	0.071
9	Overall	0.567	0.397-0.738	100.00	512.51	44	0.000	91.4%	6.51	0.000

**I^2: the variation in SMD attributable to heterogeneity; between group heterogeneity not calculated; only valid with inverse variance method

*Because the fixed-effect model was used for the data calculation of the flipped classroom, interactive approach, and video, no Tau-squared data were generated through Stata 14.0.

Table 5. A Summary of Hypothesis Testing Results

N	Null Hypotheses	Results
Considering meta-analytic results with Subgroup 3 as the variable:		
1	Interactive technologies could not significantly improve attitudes at the .05 level in language education.	Rejected
2	Interactive technologies could not significantly enhance learning motivation at the *.05* level in language education.	Accepted
3	Interactive technologies could not significantly improve self-efficacy at the *.05* level in language education.	Rejected
4	Interactive technologies could not significantly improve learning achievements at the *.05* level in language education.	Accepted
5	Interactive technologies could not significantly improve listening skills at the *.05* level in language education.	Rejected
6	Interactive technologies could not significantly improve speaking skills at the *.05* level in language education.	Accepted
7	Interactive technologies could not significantly improve reading skills at the *.05* level in language education.	Rejected
8	Interactive technologies could not significantly improve writing skills at the *.05* level in language education.	Rejected
9	Interactive technologies could not significantly improve vocabulary level at the *.05* level in language education.	Rejected
10	Interactive technologies could not significantly improve grammar level at the *.05* level in language education.	Rejected
11	Interactive technologies could not significantly improve overall learning outcomes at the *.05* level in language education.	Rejected
Considering meta-analytic results with Subgroup 4 as the variable:		
12	Flipped classroom models in interactive technologies could not have a significant impact on language education at the *.05* level.	Rejected
13	Games in interactive technologies could not have a significant impact on language education at the *.05* level.	Accepted
14	Interactive approaches in interactive technologies could not have a significant impact on language education at the *.05* level.	Accepted
15	Mobile in interactive technologies could not have a significant impact on language education at the *.05* level.	Rejected
16	Multimedia in interactive technologies could not have a significant impact on language education at the *.05* level.	Rejected
17	Technologies-assisted tools in interactive technologies could not have a significant impact on language education at the *.05* level.	Rejected
18	Videos in interactive technologies could not have a significant impact on language education at the *.05* level.	Rejected
19	Voice-assisted technology in interactive technologies could not have a significant impact on language education at the *.05* level.	Accepted
20	All kinds of interactive technologies could not have a significant impact on language education at the *.05* level.	Rejected

This finding suggests that the effect of language education in the group that is assisted by all kinds of interactive technology is higher than in the control group. Consequently, we reject Hypothesis 20.

DISCUSSION

In recent years, interactive technologies have significantly influenced language learning outcomes in education. With technological advancements, these tools have continuously evolved, making them more effective in language education. To gain a comprehensive understanding of their impact, our study integrated the findings of multiple prior studies and conducted a meta-analysis with two subgroups as variables. Our analysis looked at two main aspects. First, we examined the influence of interactive technologies on different aspects of language education. Second, we evaluated how different types of interactive technologies impact language education. By considering these perspectives, our meta-analysis provided a comprehensive understanding of the role of interactive technologies in language education.

Interactive technologies have been found to significantly improve students' attitudes toward language learning. This conclusion aligns with research conducted by Kocaman and İskender (2016), which showed that students who engage with language lessons through interactive tools exhibit more positive attitudes. Interactive technologies, especially games, provide an engaging environment that is more appealing than traditional classrooms. This atmosphere can help to reduce students' shyness and awkwardness during language communication, encouraging them to express themselves more freely (Reinders & Wattana, 2012). Furthermore, interactive technologies can help to reduce reluctance toward language learning and enhance students' perception of the learning environment (Yükseltürk et al., 2018).

Unfortunately, interactive technologies do not significantly improve learning motivation. For high-performing students, their pre-existing strong motivation was primarily due to their love for the language, not necessarily interactive tools (Sun, 2022). Long-term cultivation of motivation is essential, but research was limited by COVID-19 policies, which led to insignificant results (Adel, 2023). On the other hand, interactive technologies significantly enhance students' self-efficacy. This aligns with findings by Wu and Zhang (2009). Interactive tools provide a learning environment beyond classroom constraints, enabling students to receive positive feedback from peers and improve self-efficacy (Dai et al, 2023). The virtual environment removes face-saving concerns, enabling students to promptly solve problems with online resources (Qiu, 2017).

Although interactive technologies have the potential to improve students' self-efficacy, some studies have found no significant differences in learning achievements when individuals use these technologies (Sarabchian, 2021). One possible explanation is that interactive technologies may not always be engaging and, if students find them unenjoyable, they may discontinue using them. Additionally, students may spend a significant amount of time getting used to the technology, which could detract from their learning progress. Furthermore, language learning involves multiple aspects such as vocabulary, reading comprehension, and writing skills (Wei, 2023). However, some studies have only examined a limited number of these components, which could lead to inconsistencies and heterogeneity in the results of meta-analyses. Therefore, more comprehensive studies are needed to fully understand the impact of interactive technologies on language learning achievements.

The finding that interactive technologies can significantly improve students' listening skills aligns with the research results of Yasin et al. (2018). This is because using visual and interactive techniques can create more beneficial listening and speaking environments for students. By doing so, it can liven up the atmosphere and stimulate their interest in listening (Kılıç, 2020; Yang, 2022). Additionally, interactive technologies can provide a wide range of diverse and standardized listening materials, allowing students to enhance their listening skills in a relaxed manner (J. Zhang, 2020). Therefore, interactive technologies have the potential to significantly improve students' listening skills.

Interactive technologies have significantly improved students' listening skills, but their impact on speaking skills has been limited. One explanation is the small sample size of some studies, preventing statistical significance. Other studies have condensed complex speaking contents into short modules, facilitating language learning. However, this approach may have a greater impact on students without prior knowledge. Additionally, some models (Praat, 2014) have limitations like an inability to compare with standard pronunciation, which could affect speaking skills (Jiang, 2017; Prefume, 2015).

Interactive technologies significantly improve students' reading skills. This finding aligns with the research of Su (2009) on technology-assisted language learning models, which enhance reading proficiency. Interactive tools, such as videos and images, support inductive learning, constructing key concepts for long-term memory and reading ability (Khadragy, 2016). These technologies activate vocabulary and story plot memories, sparking students' interest and enhancing reading skills by using "schema structures" (Cloe, 2012). Moreover, interactive technologies significantly improve writing skills. This aligns with an experiment by Guo and Jia (2009), showing that students using information technology make notable progress in writing ability. Interactive technologies create a persuasive communication environment where students form writing communities to share experiences, thereby enhancing writing skills (Idrees, 2017). Technologies also support planning, supervision, and evaluation of writing procedures. Drawing interactive mind maps broadens perspectives and focuses on writing layout, increasing metacognition (Y. Liang, 2021).

Interactive technologies, such as animations, significantly improve students' vocabulary levels, aligning with findings of Rahimi et al. (2021). These tools enhance delayed memory and improve students' perception, understanding, and application of vocabulary (Ma, 2023). Interactive technologies also strengthen students' senses, promoting cognitive activities and improving vocabulary levels (Tang, 2012). Additionally, interactive technologies can significantly enhance students' grammar skills. Karimova et al. (2023) and Lopez Vera (2022) have both demonstrated the positive impact of interactive technologies on L2 grammar acquisition. In comparison to traditional methods that often rely on forced input and memorization, interactive technologies introduce more diverse and engaging task-driven learning paradigms. These approaches encourage students to collaborate and think critically and repetitively, which in turn enhances their grammar learning motivation (R. Wang, 2022). Furthermore, interactive technologies effectively bridge the gap between students' existing grammar knowledge and new concepts, thus building a more coherent and systematic knowledge system (Shen, 2021).

Language learners, especially digital natives, embrace interactive technologies (Prensky, 2001), opening new education opportunities (X. Chen, 2013). These tools foster creative thinking and can enhance creative writing, listening, and reading abilities in digital environments (Selfa-Sastre et al., 2022). Integrating avatars in learning materials not only enhances cognitive ability but also self-efficacy and attitudes (Peixoto et al., 2021), highlighting the impact of interactive technologies on language learning outcomes.

The flipped classroom model has a positive impact on language education, aligning with findings of C. Chen (2015). It promotes active learning by enhancing opportunities for autonomous participation, outputs, and interactions (Prefume, 2015). This model enhances language learning levels both inside and outside the classroom through methods like role-playing, group tasks, peer evaluation, and entertainment like videos and games (Sun, 2022). However, games alone do not significantly improve language education. Interactive games' performance measurements vary, leading to diverse research outcomes. For instance, a study by Yan (2019) used points and levels, while others used leaderboards and digital badges. Additionally, the appeal of games varies among age groups. The focus of Sarabchian (2015) on third and fourth-graders might explain the insignificant results to some extent.

The interactive approach has not significantly enhanced language education, as research shows (Adel, 2023). It is hindered by the need for extensive programming tools for integrating games, collaborative discussions, and assessments. Additionally, one study lacks sufficient data due to small sample sizes, leading to inconclusive results (Cloe, 2012). Mobile technology, however, effectively enhances language education. Findings support this conclusion (Abdou, 2014). Mobile online courses eliminate distance barriers, enhancing learning convenience and efficiency (Bu, 2023). Digital tools like flashcards and e-learning apps provide detailed student records and analytics, enabling teachers to deliver targeted content based on data (Zakian et al., 2022).

Multimedia and technology-assisted tools significantly enhance language education. Some research underscores the potential of multimodal design for improving learners' language performance (J. Liang & Hwang, 2023). Multimedia combines sound, animation, graphics, subtitles, and videos, offering a realistic language communication context and global learning environment (He, 2008). Compared to text learning, multimedia can more intuitively present complex information, helping students understand and grasp the language (Ma, 2023). Technology-assisted tools also significantly improve language education, aligning with findings that such tools enhance students' language learning outcomes (Cho, 2021). These tools provide timely feedback and personalized learning environments, enhancing language learning effectiveness and efficiency (Wei, 2023). Platforms like educational interaction platforms offer a wealth of language education-related information, enabling students to access vast amounts of learning resources and promoting educational informatization (Yang, 2022).

Video-based learning can significantly enhance language education. This conclusion is consistent with research that found videos to be a beneficial tool for language instruction (Shi, 2012). Videos combine audio and visual elements, thereby enhancing students' language comprehension. Additionally, videos facilitate the organization of language-related knowledge points, making it easier for students to access lecture notes (Rahimi et al., 2021). Furthermore, videos have the potential to ignite students' enthusiasm for language learning and prompt self-reflection on language-related shortcomings (R. Wang, 2022). However, voice-assisted technology has limited impact on language education. When it comes to training in pronunciation discrimination, voice-assisted education fails to captivate students' interest, leading them to treat technology-based tasks as routine classroom assignments. This may negatively impact test results (R. Wang, 2022). Moreover, many studies have focused on specific grades or affluent regions, limiting the generalizability and significance of their findings (R. Wang, 2022; Dunn, 2012).

Despite certain interactive technologies having a limited impact on language education, numerous others offer significant benefits. The evolving nature of interaction technology presents both opportunities and challenges for educators. They must carefully select technologies based on their unique features and potential to enhance language learning. For instance, flipped classroom technology enables knowledge sharing and resources, supporting learners' independent exploration (Moradi & Chen, 2019). Other interactive technologies, such as mobile learning and gaming, can enhance online learning experiences, combining online and offline courses to enhance language learning efficiency (Selfa-Sastre et al., 2022).

CONCLUSION

Major Findings

This study used meta-analysis to examine the impact of interactive technologies on various aspects of language education, including different types of technologies. To put it in a nutshell, although learning achievements, speaking skills, and learning motivation were not significantly influenced by interactive technologies, they had a significant impact on overall learning outcomes. Furthermore, various types of interactive technologies, including flipped classroom models, mobile, multimedia, technology-assisted tools, and videos, have shown promise in improving language education.

Research findings strongly confirm the promoting effect of interactive technologies on language education and, more importantly, they also prompt us to delve into the exceptions. On the one hand, the multimodal, immersive, and collaborative features of interactive technologies exert substantial impacts on language learners. On the other hand, due to numerous implicit components of learning achievements and motivation, and the difficulty in establishing a unified evaluation standard for them, the impact of interactive technologies on them is difficult to significantly demonstrate through result data. Additionally, interactive technologies such as games, have hidden dangers such as distracting students' attention, cumbersome design processes, and delaying classroom time. If they are not properly applied, they may have insignificant or even negative effects on language learning.

Limitations

This study has several limitations. First, much of the data collection for the meta-analysis was obtained from papers on Web of Science and CNKI, with only a small amount from other academic websites. This may lead to incomplete and noncomprehensive data. Second, due to regional restrictions and limitations in research resources provided by the university, our meta-analysis finally included 45 articles, which may be a relatively small quantity. Meanwhile, two-thirds of these articles are English literature, while the rest are Chinese literature, which may lead to a lack of universality in the results. Third, the research data did not include books and conference articles, which could potentially bias the results. Finally, for a single study, proposing 20 null hypotheses at once to explore the impact of interactive technologies on language education from two aspects may be relatively broad, and so it may be a bit hard to achieve ideal results.

Future Research Prospects

We recommend that educators approach interactive technologies in language education with caution and strategic intent. While these tools offer the potential to enhance students' language skills, their use must be balanced. On one hand, interactive technologies can improve students' listening, reading, writing, grammar, and vocabulary. By harnessing their capabilities, teachers can foster positive learning attitudes and self-efficacy among learners. For instance, videos, mobile apps, multimedia resources, flipped classroom models, and technology-assisted tools can be effectively utilized to achieve targeted language education outcomes. However, it is essential to consider the potential downsides of interactive technologies. Some students may feel uncomfortable operating digital devices or find the time commitment overwhelming. Virtual environments have the potential to distract students from their learning objectives. Therefore, educators must exercise caution in their implementation. Moreover, previous research has often been limited. Future studies should expand their scope to establish the effectiveness and universality of interactive technologies in language education more robustly.

In light of the potential challenges posed by interactive technologies, educators should approach their integration dialectically. Some students may struggle with digital devices, and time-consuming interactive technologies can be a drain on class time (Jackson & McNamara, 2013; Tao, 2023). Additionally, virtual scenes—created through visuals, videos, and sound—may prove distracting to students (Liu et al., 2023). As such, the application of interactive technologies in language education may not always enhance learners' motivation and interest. To this end, educators should exercise caution when implementing these tools. Furthermore, past research has often been limited in scope, focusing on specific grades, schools, or regions (Dunn, 2012; J. Zhang, 2020. Therefore, future research efforts should aim to expand the scope of their investigations and ensure that data collection is both effective and representative.

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