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REGULAR ARTICLE

Tracking the Effects of Gemini as a GenAI Tool on L2 Learners' Writing Proficiency and Anxiety: Latent Growth Curve Modeling Approach

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Abstract The emergence of generative artificial intelligence (GenAI) tools in second and foreign language (L2) contexts has introduced new possibilities for second language acquisition (SLA). While preliminary studies have highlighted the potential of GenAI technologies, there remains a notable gap in empirical evidence concerning how such technologies influence the cognitive and affective aspects of L2 learning. Moreover, most existing studies have relied on cross-sectional designs, overlooking the evolving nature of L2 learners' cognitive and affective development. To bridge these gaps, this longitudinal study harnessed the latent growth curve modeling (LGCM) approach to track the sustained effects of Gemini on L2 learners' writing proficiency and anxiety. The study involved 274 undergraduate English learners enrolled in four academic writing classes at a public university in Iran. Participants were randomly assigned to either a treatment group ($n = 151$), which received GenAI-assisted instruction using Gemini, or a control group ($n = 123$), which received traditional instruction, over a 16-week course. The writing proficiency of the participants was measured using a standardized rubric-based assessment, and their writing anxiety was assessed through an L2 writing anxiety scale. The LGCM outcomes revealed significant growth in the writing proficiency of the treatment group ($MD = 4.49$, $SE = 0.181$, $CR = 24.84$, $p < .001$), alongside a marked decrease in their writing anxiety ($MD = –5.42$, $SE = 0.114$, $CR = 47.48$, $p < .001$). Together, the findings underscore the pedagogical value of integrating GenAI tools like Gemini into L2 writing instruction, as they offer tailored, immediate feedback that enhances learners' proficiency while alleviating their writing-related anxiety.

Keywords Generative artificial intelligence (GenAI) · Writing anxiety · Writing proficiency · Latent growth curve modeling (LGCM) · L2 learners

Introduction

In recent years, the rapid evolution of generative artificial intelligence (GenAI) has significantly influenced educational practices, particularly in the field of second and foreign language (L2) learning (Chen et al., 2025; Derakhshan & Taghizadeh, 2025; Liu & Fan, 2024; Liu et al., 2025; Yang & Zhao, 2024; Zhang et al., 2025; Zong & Yang, 2025). With the emergence of advanced language models, L2 learners are now able to engage with intelligent tools that can assist them in generating, editing, and refining their written output (Zare et al., 2025). These technologies offer learners real-time feedback, context-sensitive suggestions, and exposure to authentic language use, thereby reshaping the traditional dynamics of L2 writing instruction (Barrot, 2023). Given the accelerating integration of GenAI tools like Gemini into L2 writing classrooms, there is a growing need to systematically investigate how such technologies influence L2 learners' writing skills and their emotional responses—particularly anxiety, which has been shown to hinder academic success in L2 learning environments (Güvendir & Uzun, 2023).

Writing is one of the most cognitively demanding skills in L2 learning, requiring the integration of linguistic, rhetorical, and metacognitive abilities (Cumming, 2016). Developing proficiency in L2 writing is often a prolonged and

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effortful process that poses significant challenges for learners at various proficiency levels (Kormos, 2012). Alongside these linguistic difficulties, many learners experience writing anxiety, which is a negative emotional state characterized by fear, apprehension, and avoidance of writing tasks (Cheng, 2002). Writing anxiety has been widely documented as a barrier to successful performance in L2 writing classes (Hui-Fang, 2013), often leading to reduced academic motivation, decreased classroom engagement, and lower learning outcomes (Güvendir & Uzun, 2023). In this regard, the emergence of GenAI tools such as Gemini offers a potentially transformative avenue for supporting L2 learners' writing development (Zhang et al., 2025). These tools provide automated feedback, linguistic suggestions, and structural guidance throughout the writing process (Tiandem-Adamou, 2024), which may lessen learners' cognitive load and improve their writing proficiency. By enhancing learners' control over language production (Nelson et al., 2025), these tools may also reduce their writing-related anxiety.

The influence of GenAI on L2 learners' writing proficiency and anxiety can be effectively interpreted through the lens of Vygotsky's sociocultural theory (SCT), which posits that learning occurs through mediated interactions within the zone of proximal development (ZPD) (Vygotsky, 1978). Traditionally, teachers and peers have served as more knowledgeable others (MKOs), scaffolding learners' progress through feedback and modeling. With the advent of GenAI tools such as Gemini, this scaffolding can now be delivered by intelligent systems that offer real-time, adaptive support aligned with learners' developmental needs (Al-Kadi & Ali, 2024). By providing personalized feedback on language use, structure, and organization (Guo et al., 2022), these tools can help learners internalize complex writing skills, thereby enhancing their proficiency. Simultaneously, by serving as nonjudgmental and readily available MKOs, GenAI tools may alleviate writing-related anxiety by reducing fear of negative evaluation and increasing learners' confidence (Nelson et al., 2025).

Despite their promise, the extent to which GenAI tools can foster writing proficiency while alleviating writing anxiety remains an open empirical question. Previous studies on GenAI tools have generally explored the perceived advantages and disadvantages of these technologies in L2 classrooms (Dai & Liu, 2024). While these investigations have provided valuable insights, they tend to remain largely descriptive, offering limited empirical evidence on actual learner outcomes (Wang et al., 2025). Moreover, a number of studies examining the impact of GenAI tools on L2 writing performance and anxiety have adopted short-term or cross-sectional designs (Hawanti & Zubaydulloevna, 2023; Kartika, 2024; Tiandem-Adamou, 2024), which fail to capture how L2 learners' writing proficiency and anxiety change over time in response to continuous engagement with these advanced tools. Additionally, to the author's knowledge, no study has examined the simultaneous development of writing proficiency and anxiety within the same group of learners, making it difficult to determine whether improvements in one area coincide with changes in the other.

To address these gaps, this study sets out to evaluate the long-term effects of Gemini, a GenAI-powered writing assistant, on L2 learners' writing proficiency and writing anxiety. Specifically, drawing on the latent growth curve modeling (LGCM) approach, the study seeks to track changes in these variables across three time points during a semester-long writing course. This dual-focus approach enables the simultaneous examination of cognitive and affective trajectories, providing a more comprehensive understanding of how GenAI tools shape the L2 writing experience over time. By doing so, the study contributes to a more nuanced and data-driven understanding of GenAI's pedagogical impact, offering practical implications for language educators and curriculum designers seeking to leverage GenAI technologies to enhance learners' performance and emotional experiences in L2 writing classes.

Literature Review

GenAI in L2 Education

Generative artificial intelligence (GenAI) refers to a set of AI systems designed to produce human-like content based on user input, including text, images, and audio (Ronge et al., 2025). These advanced systems are powered by large-scale language models (LLMs) trained on vast amounts of data and are capable of generating coherent, contextually appropriate responses (Ronge et al., 2025). Well-known GenAI applications currently used in educational contexts include Gemini (Google), ChatGPT (OpenAI), and Claude (Anthropic), each offering interactive, text-based support for a wide range of learning activities, such as brainstorming, content summarization, grammar correction, and dialogue simulation (Wang, 2024).

In the context of L2 education, GenAI tools offer new possibilities for reshaping how learners acquire and use language. Their capacity to generate personalized input, model authentic language use, and provide immediate feedback has positioned them as promising tools for both teachers and learners (Law, 2024; Soyoof et al., 2025). Unlike traditional digital learning tools, GenAI can engage users in dynamic, interactive exchanges, enabling them to explore vocabulary, grammar, and discourse structures in real time (Law, 2024). These features can contribute to more learner-centered instruction and promote greater autonomy in language practice (Tu et al., 2025), particularly in environments where access to expert guidance may be limited.

However, despite growing interest in the integration of GenAI into L2 classrooms, empirical research into its pedagogical effects remains limited. Most existing studies have focused on learners' and teachers' attitudes towards GenAI tools or the ethical concerns and technological capabilities of these tools (Xin & Derakhshan, 2025), rather than systematically assessing their impact on L2 development. This gap highlights the need for more focused investigations into how GenAI shapes productive and receptive language skills over time.

Writing Proficiency

Writing proficiency is widely acknowledged as one of the most complex and demanding skills to develop in L2 learning. Unlike receptive skills such as listening and reading, writing requires learners to produce language actively while attending to multiple linguistic, cognitive, and rhetorical demands simultaneously (Kormos, 2012). In the present study, writing proficiency includes clarity of expression, organization, development of ideas, and grammatical accuracy (Cumming, 2016). Accordingly, writing proficiency encompasses not only linguistic competence but also the ability to organize ideas, employ appropriate textual structures, and adapt tone and register to communicative goals (Cumming, 2016).

Mastering L2 writing proficiency is often a gradual process, shaped by a range of individual and contextual factors such as language background, motivation, exposure to written input, and instructional quality (Ouyang et al., 2022). For many learners, the cognitive load involved in generating coherent and accurate written texts in a non-native language can be overwhelming, particularly at lower proficiency levels (Phuoc & Barrot, 2022). Moreover, the lack of immediate feedback during the writing process can hinder learners' ability to monitor and revise their work effectively, resulting in fossilized errors and limited progress over time (Phuoc & Barrot, 2022). As a result, supporting L2 writers through timely, individualized, and scaffolded feedback has become a central concern in both research and practice.

In recent years, technological tools have been increasingly leveraged to support L2 writing instruction, ranging from automated writing evaluation systems (e.g., Grammarly, Criterion) to more advanced AI-based writing assistants (e.g., Gemini, ChatGPT) (Zou & Huang, 2024). These technologies aim to reduce the burden of error correction for instructors and provide learners with instant, context-sensitive feedback on various aspects of their writing (Zou & Huang, 2024). While such tools have shown promise in improving overall writing proficiency (Yan, 2023), questions remain about their effectiveness in fostering different writing skills, notably higher-order skills such as organization, argumentation, and coherence (Guo et al., 2022). This underscores the need to further explore how emerging technologies—particularly GenAI tools—can meaningfully contribute to L2 writing proficiency.

Writing Anxiety

Writing anxiety refers to the apprehension, fear, or tension that individuals experience when required to produce written text (Cheng, 2002). In L2 contexts, writing anxiety is particularly prevalent and can significantly hinder learners' academic motivation and performance (Wang et al., 2025). Unlike speaking-related anxiety, which is typically situational and momentary, writing anxiety tends to be more enduring, often rooted in past experiences of negative feedback, linguistic insecurity, or perceived incompetence (Güvendir & Uzun, 2023).

In the current research, L2 writing anxiety is considered as a multifaceted construct with three distinct dimensions: somatic anxiety (physical symptoms such as nervousness), cognitive anxiety (worry and negative thoughts about writing performance), and behavioral anxiety (procrastination or reluctance to write) (Cheng, 2017). These factors, as put by Cheng (2017), can impair learners' ability to plan, compose, and revise texts effectively, thereby limiting the quality of their writing. High levels of anxiety have also been linked to reduced writing fluency, limited lexical and syntactic complexity, and a tendency to avoid challenging tasks (Güvendir & Uzun, 2023; Wang et al., 2025).

While a number of pedagogical approaches—such as process-oriented writing instruction, peer feedback, and anxiety-reduction workshops—have been used to help learners manage their writing anxiety, the potential of emerging technologies to address this issue remains relatively underexamined. As such, there is a pressing need for studies that systematically explore whether and how sustained engagement with new technologies like GenAI tools can help alleviate L2 writing anxiety.

The Role of GenAI in Shaping L2 Learners' Writing Proficiency and Anxiety

The influence of GenAI on L2 learners' writing proficiency and anxiety can be conceptualized through the lens of Vygotsky's SCT. SCT emphasizes the fundamentally social nature of learning (Vygotsky, 1978), positing that cognitive development occurs through mediated interactions with MKOs within the learner's ZPD—the range between what learners can do independently and what they can achieve with guidance (Vygotsky, 1978). In L2 writing classrooms, the MKO traditionally takes the form of teachers or peers who scaffold learners' efforts by providing feedback, modeling language use, and facilitating reflection.

With the rise of GenAI tools such as Capilot, ChatGPT, and Gemini, these technologies have begun to assume the role of an accessible and responsive MKO, offering personalized support that aligns with learners' current developmental needs (Al-Kadi & Ali, 2024). These tools provide real-time feedback on grammar, vocabulary, organization, and style, allowing learners to engage in scaffolded writing tasks that stretch their abilities just beyond independent performance (Guo et al., 2022). This dynamic interaction within the ZPD can improve writing proficiency by enabling learners to internalize linguistic structures and rhetorical strategies through guided practice (Do, 2025). Moreover, by serving as a nonjudgmental, always-available MKO (Nelson et al., 2025), these tools may reduce writing-related anxiety, which often stems from fear of negative evaluation and perceived linguistic incompetence.

Building on these theoretical foundations, this study aims to investigate how Gemini functions as an MKO in supporting L2 learners' writing proficiency and reducing their writing-related anxiety. The investigation was framed around the following research questions:

- In what direction do L2 learners' writing proficiency and anxiety change throughout the semester?
- How does Gemini influence L2 learners' writing proficiency and anxiety?

Method

This experimental research harnessed a quantitative "repeated measures design" (RMD) to capture the effects of Gemini, a GenAI writing assistant, on L2 learners' writing proficiency and anxiety over time. The RMD framework allowed for the observation of intra- and inter-individual changes across three measurement points—pre-intervention, mid-intervention, and post-intervention—within a 16-week academic writing course.

Participants

The participants in this study were 274 undergraduate students enrolled in four academic writing classes at a public university in Iran. Students in all writing classes were informed about the purpose and scope of the research. They were assured that their participation was entirely voluntary and that they could withdraw at any point without academic penalty. Written informed consent was also obtained from all participants. After consent was secured, they were randomly assigned to either the treatment or control condition using a computerized random number generator. This procedure resulted in 151 participants being allocated to the treatment condition, who engaged with the GenAI tool (Gemini) during the writing course, and 123 participants assigned to the control condition, who received traditional writing instruction without GenAI support. All participants were majoring in "Teaching English as a Foreign Language" (TEFL). The sample included 85 males and 189 females, with ages ranging from 20 to 23 years ($\bar{x}=22$).

Measures and Instruments

L2 Writing Anxiety Scale (L2WAS)

Writing anxiety was measured using "L2 Writing Anxiety Scale" (L2WAS) (Cheng, 2017), a widely validated instrument designed to assess anxiety specifically related to L2 writing. The scale consists of nine items rated on a Likert-type scale ranging from 1 "strongly disagree" to 5 "strongly agree". Sample items include statements such as "When writing in English, I often feel my heart pounding" (Item 4) and "When writing in English, I often sweat and perspire" (Item 6). In the present study, the scale exhibited a Cronbach's alpha of 0.89, indicating satisfactory internal consistency.

CUNY Assessment Test in Writing (CATW)

Writing proficiency was assessed using the "CUNY Assessment Test in Writing" (CATW). The CATW is a well-established standardized test designed to evaluate students' ability to compose a well-organized essay in response to a prompt. The test consists of two parts: a reading passage of approximately 300 to 350 words, followed by detailed writing instructions intended to guide test-takers in formulating their responses. The CATW assesses multiple critical aspects of writing proficiency, including "clarity of expression", "organization", "development of ideas", and "grammatical accuracy". Scoring is conducted using an analytic rubric, which breaks down the essay into distinct criteria, enabling raters to evaluate each dimension of writing proficiency independently. Students were given 90 min to complete the test and were permitted to consult a non-electronic dictionary, including bilingual versions, to support their writing process.

Gemini: A GenAI-Powered Tool

Gemini, developed by Google DeepMind, is a GenAI platform designed to assist users in producing, revising, and evaluating written texts across a range of genres (Do, 2025). In this study, Gemini was selected as the sole GenAI writing assistant due to its potential to offer context-sensitive feedback, linguistic suggestions, and structural guidance. Compared to other tools such as ChatGPT or Copilot, Gemini appears to provide relatively tailored support for academic

writing, particularly through its capacity to generate real-time feedback on cohesion, coherence, and organization (Al-Kadi & Ali, 2024). Its intuitive interface and responsiveness made it suitable for continuous classroom use, allowing learners to iteratively improve their writing performance with minimal technical barriers (Kartika, 2024). While its performance may vary depending on task complexity and user proficiency, Gemini arguably functions as a mediational tool that aligns with sociocultural principles of learning, potentially supporting learners' cognitive development and alleviating their anxiety through nonjudgmental, responsive interaction.

Procedure

The study was conducted over the course of a 16-week academic semester. During the first week, participants in all three writing classes were informed about the purpose of the research and provided written consent to participate. They were then randomly assigned to either the treatment or control group. To minimize potential contamination between these groups, instructional sessions for the treatment and control groups were conducted separately, and participants were instructed to refrain from sharing materials or discussing the intervention outside of class.

Furthermore, to control for potential confounding variables, several procedural safeguards were implemented. Both groups were taught by the same instructor, followed an identical syllabus, used the same course materials, and participated in the same number of instructional hours. The only systematic difference between the groups was the use of Gemini in the treatment condition. Learners in the treatment group were encouraged to use this GenAI tool during different phases of the writing process (i.e., brainstorming, drafting, revising, and editing), whereas the control group completed all writing tasks independently, without any technological assistance.

In order to track the impact of the intervention over time, data were collected at three intervals: at the beginning of the semester (Week 1), the midpoint (Week 8), and the end of the semester (Week 16). At each time point, all participants completed the CATW and the L2WAS. For the sake of reliability, these assessments were administered under standardized conditions across both groups.

Data Analysis

To address the research questions, both descriptive and inferential statistical analyses were conducted. Initially, descriptive statistics were calculated to observe general trends across the three assessment points (pretest, midtest, and posttest). Then, to model the developmental trajectories of learners' writing proficiency and anxiety, the LGCM was conducted using structural equation modeling (SEM). Unlike conventional pretest–posttest designs, LGCM enables the modeling of learners' growth trajectories over multiple time points, allowing us to estimate both the initial status (intercepts) and the rate of change (slopes) for writing proficiency and anxiety. This approach captures not only average developmental trends across the entire sample but also inter-individual variability in these trajectories (Bollen & Curran, 2006), thus offering a more nuanced picture of learner development. Moreover, LGCM allows for the simultaneous examination of the dynamic interplay between writing proficiency and anxiety over time, providing insights into whether changes in one construct are systematically associated with changes in the other (Duncan & Duncan, 2004). By leveraging these strengths, LGCM moves beyond static comparisons and enables a developmental perspective that better aligns with the aims of this study. Following that, to determine the effectiveness of the treatment, mean changes in slope values were compared across groups. The data analysis was done using IBM SPSS (version 26) and IBM AMOS (version 26).

Results

Following the three assessment points, total scores from the L2WAS were used to represent participants' writing anxiety levels. For writing proficiency, scores assigned by two trained raters were summed, with the first three dimensions of the CATW rubric weighted twice in accordance with official scoring guidelines. Descriptive statistics for both writing and anxiety scores across time points are presented in Table 1.

As shown in Table 1, the treatment group exhibited a clear upward trend in writing scores and a corresponding downward trend in anxiety scores across the three time points. A similar pattern was observed in the control group, although the magnitude of change was notably smaller. To address the first research question, an LGCM was constructed, which is presented in Fig. 1.

The LGCM was conducted separately for the treatment and control groups. In creating the model, we followed Kline's (2012) instructions. In each model, the intercepts (ICEPTs) represented participants' baseline scores across the three measurement points, while the slopes (SLOPEs) captured the rate and direction of change. Covariances between the two ICEPTs assessed the initial relationship between the variables, and covariances between the two SLOPEs examined the degree to which changes in writing proficiency and anxiety were interrelated. The standardized results of the measurement models for both the treatment and control groups are illustrated in Fig. 2, and the detailed outputs of the SEM analysis are presented in Table 2.

Table 1 Descriptive statistics of scores

Group		N	Minimum	Maximum	Mean	Std. Deviation	Skewness
CT	Anxiety1	123	13	45	25.31	5.977	.875
	Anxiety2	123	13	44	24.20	5.835	.964
	Anxiety3	123	13	42	23.49	5.712	.981
	Writing1	123	62	89	75.46	5.422	−.258
	Writing2	123	62	92	75.33	5.794	−.076
	Writing3	123	64	91	75.68	5.649	−.130
TG	Anxiety1	151	11	43	27.25	5.910	.154
	Anxiety2	151	9	42	21.60	5.698	.649
	Anxiety3	151	8	40	20.65	5.761	.462
	Writing1	151	65	88	77.05	4.738	−.222
	Writing2	151	65	92	82.67	5.906	−.283
	Writing3	151	68	92	83.56	5.798	−.324

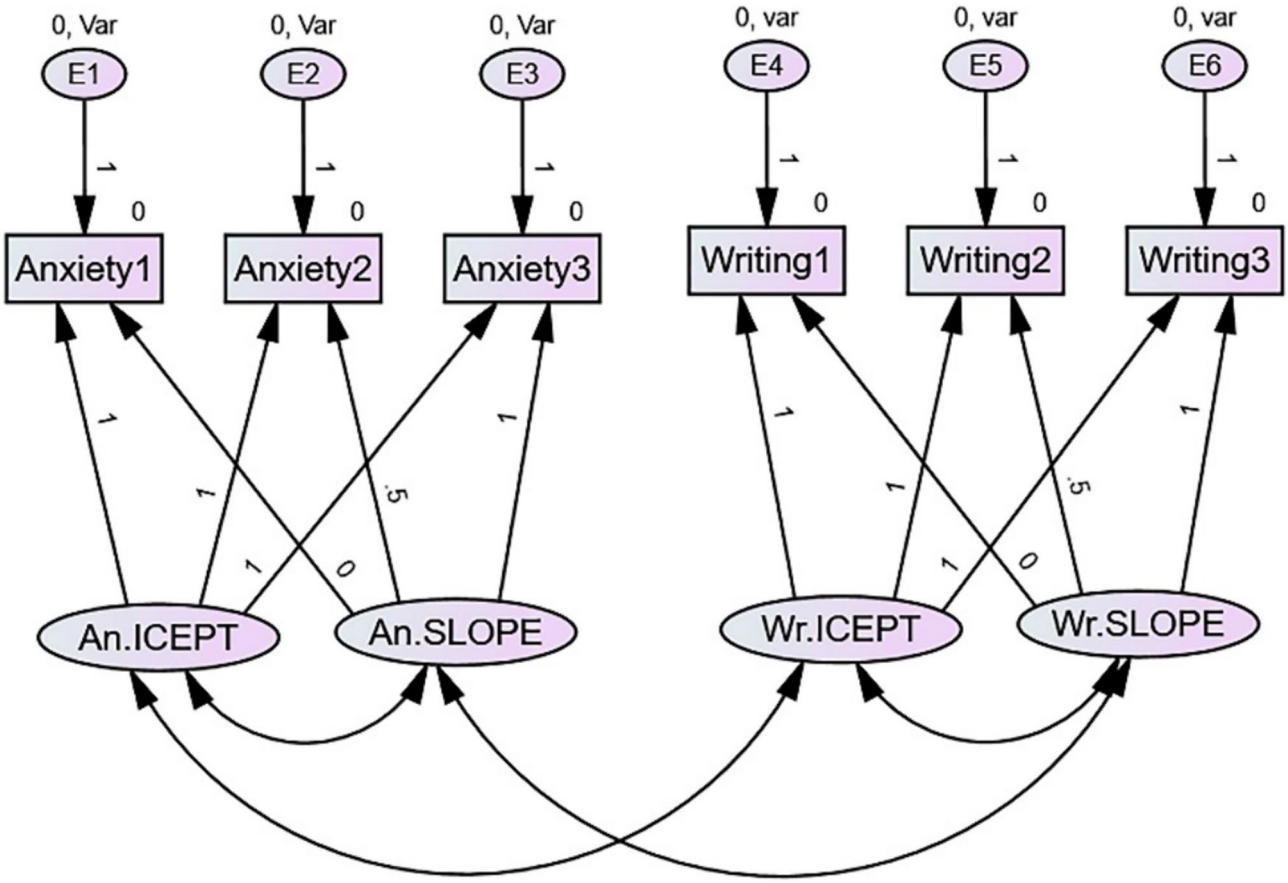

Fig. 1 Proposed LGCM model for the change in anxiety and writing scores

As shown in Table 2, the LGCM results revealed significant variance in both the ICEPTs and SLOPEs of writing proficiency and anxiety scores for both the treatment and control groups. These findings suggest substantial individual variability in initial performance as well as in developmental trajectories over time. Moreover, in the treatment group, a significant negative covariance was found between the SLOPEs of writing proficiency and anxiety ($r = -.156$, $p < .001$), indicating that learners who demonstrated greater improvements in writing tended to show larger reductions in writing anxiety.

To address the second research question, changes in the mean slope values for writing proficiency and anxiety were examined across both groups. As reported in Table 2, the control group did not exhibit statistically significant changes over time in either writing proficiency (Wr.SLOPE) or

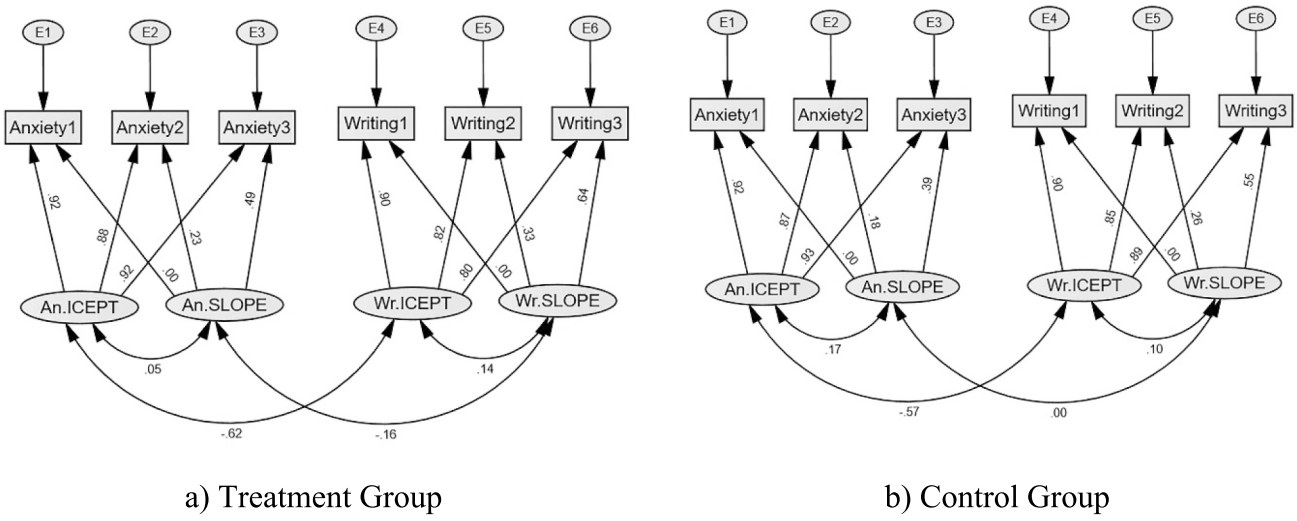

Fig. 2 LGCM Model with standardized estimates

Table 2 Variance, Covariances, and Mean Values for the LGCM Model

Group					Unstandardized				Stand-ardized estimates
					Estimate	S.E	C.R	P	
CT	Covariances	Wr.ICEPT	<–>	Wr.SLOPE	1.627	.720	2.259	.024	.103
		An.ICEPT	<–>	An.SLOPE	2.113	.613	3.449	.000	.172
		Wr.SLOPE	<–>	An.SLOPE	.022	.181	.119	.905	.003
		Wr.ICEPT	<–>	An.ICEPT	−15.408	3.126	−4.929	.000	−.566
	Variances	Wr.ICEPT			25.323	3.766	6.725	.000	
		Wr.SLOPE			9.819	1.146	8.565	.000	
		An.ICEPT			29.248	4.269	6.851	.000	
		An.SLOPE			5.162	.831	6.210	.000	
	Means	Wr.SLOPE			.495	.285	1.737	.121	
		An.SLOPE			−.643	.384	−1.674	.159	
TG	Covariances	Wr.ICEPT	<–>	Wr.SLOPE	2.843	.670	4.240	.000	.139
		An.ICEPT	<–>	An.SLOPE	.879	.603	1.458	.145	.055
		Wr.SLOPE	<–>	An.SLOPE	−1.853	.312	−5.937	.000	−.156
		Wr.ICEPT	<–>	An.ICEPT	−17.212	2.157	−7.979	.000	−.622
	Variances	Wr.ICEPT			25.311	2.521	10.041	.000	
		Wr.SLOPE			16.636	1.261	13.190	.000	
		An.ICEPT			30.289	2.935	10.320	.000	
		An.SLOPE			8.495	.877	9.691	.000	
	Means	Wr.SLOPE			4.493	.181	24.849	.000	
		An.SLOPE			−5.427	.114	−47.48	.000	

Wr.ICEPT: writing intercept; Wr.SLOPE: writing slope; AnICEPT: anxiety intercept; An.SLOPE: anxiety slope

anxiety (An.SLOPE), with p values exceeding .05. In contrast, the treatment group demonstrated significant overall growth in writing proficiency ($MD = 4.49$, $SE = 0.181$, $CR = 24.84$, $p < .001$) and a significant overall reduction in writing anxiety ($MD = –5.42$, $SE = 0.114$, $CR = 47.48$, $p < .001$). Looking at the beta values for SLOPEs, it was concluded that these changes were continuous over time. This indicates that proficiency increased from the first assessment to the second, and then to the third, while anxiety decreased in a similar pattern. These results suggest that the GenAI-assisted writing instruction had a substantial and statistically significant impact, leading to measurable

improvements in learners' writing performance while simultaneously alleviating their anxiety over the course of the semester.

Finally, the generalizability of the proposed model was evaluated by examining the model fit indices. The "root mean square error of approximation" (RMSEA) was found to be 0.067, the "comparative fit index" (CFI) was 0.953, and the "Tucker-Lewis index" (TLI) was 0.947. Additionally, the standardized "root mean square residual" (SRMR) was 0.069. All of these values exceed the thresholds set by Hu and Bentler (1999) for acceptable model fit.

Discussion

This experimental study was an endeavor to examine the developmental trajectories of L2 learners' writing proficiency and writing anxiety over a 16-week academic writing course. The first objective of this research was to capture the direction and magnitude of change in these two constructs across three time points (pretest, midtest, and posttest). The second objective was to assess the impact of Gemini on these developmental patterns by comparing the performance of learners who received GenAI-enhanced writing instruction with those who underwent conventional writing instruction. By employing the LGCM approach within a repeated-measures design, the study sought to offer a longitudinal, data-driven perspective on how GenAI integration may influence both cognitive (writing proficiency) and affective (writing anxiety) dimensions of L2 writing.

Concerning the first purpose of the study, three main patterns emerged. First, learners in the treatment group demonstrated a clear upward trajectory in writing proficiency and a concurrent decline in writing anxiety over the three time points. This suggests that the use of Gemini as a writing assistant provided learners with immediate, personalized support that enhanced their writing skills while simultaneously reducing their emotional strain. In fact, the supportive nature of GenAI likely created a low-pressure learning environment where learners could experiment with language and receive constructive input without fear of judgment, thus facilitating both cognitive and emotional growth. Although the control group demonstrated similar trends, the smaller magnitude of change suggests that conventional writing instruction may not offer the same level of individualized attention and support that GenAI tools like Gemini can deliver. Second, the LGCM results exhibited significant variances in both the intercepts and slopes of writing proficiency and anxiety across both the treatment and control groups, indicating substantial heterogeneity in learners' initial standing and developmental trajectories. Such variability may be attributed to individual differences in learners' language proficiency levels (e.g., C1, C2, B1, B2), psycho-affective attributes (e.g., confidence, self-efficacy beliefs, writing apprehension), and degrees of engagement with the course materials. This result highlights that even within structured instructional contexts, learners progress at different rates and through distinct pathways, suggesting the need for pedagogical writing approaches that are flexible, adaptive, and responsive to individual learner profiles (Kormos, 2012). Third, the LGCM outcomes further revealed a significant negative covariance between the slopes of writing proficiency and anxiety in the treatment group, which suggests a dynamic, reciprocal relationship between these two constructs. Learners who made greater gains in writing proficiency experienced more substantial reductions in their writing anxiety levels. This finding is consistent with the theoretical premise that cognitive and affective variables in L2 learning are interrelated (MacIntyre & Gardner, 1991), and supports the view that increased writing competence can reduce writing-related anxiety by fostering a greater sense of control and self-confidence in learners (Cheng, 2002). Additionally, this finding is in line with previous research that has documented a robust, negative correlation between writing proficiency and anxiety (Güvendir & Uzun, 2023; Wang et al., 2025).

With respect to the second objective of the study, the results clearly indicated that the use of Gemini as a GenAI tool had a significant impact on L2 learners' writing proficiency and writing anxiety over time. While the control group did not show any statistically significant changes in either construct, the treatment group experienced substantial improvement in writing performance and a corresponding decrease in writing-related anxiety. These findings can be interpreted in light of Vygotsky's (1978) SCT, particularly the concept of the ZPD, which emphasizes the role of scaffolding in facilitating learning. In this context, Gemini functioned as an accessible and responsive MKO by offering immediate, adaptive, and individualized feedback, allowing learners to engage with L2 writing tasks just beyond their independent competence level and gradually internalize more advanced writing strategies. This ongoing scaffolding likely reduced cognitive overload and performance pressure, thereby contributing to the observed decrease in writing-related anxiety. The significant improvement in writing proficiency observed in the treatment group aligns with an expanding body of empirical research on the pedagogical potential of AI and GenAI tools (Guo et al., 2022; Kartika, 2024; Tiandem-Adamou, 2024; Yang & Zhao, 2024). Studies by Kartika (2024), Tiandem-Adamou (2024), and Zhang et al. (2025) have all reported measurable gains in learners' academic writing performance following the integration of GenAI-powered feedback. Similarly, Guo et al. (2022) found that GenAI-driven scaffolding enhanced students' ability to structure arguments, organize content, and revise effectively—skills central to L2 writing proficiency. In relation to

writing anxiety, the present findings echo those of Hawanti and Zubaydulloevna (2023), who found that chatbot-based learning environments contributed to reduced anxiety in EFL writing classrooms by creating more personalized and less judgmental spaces for practice. Likewise, Wang (2024) reported that GenAI-generated feedback was more effective than teacher-generated feedback in lowering learners' writing anxiety, suggesting that GenAI tools may mitigate emotional strain by offering immediate, non-threatening support.

Despite its valuable outcomes, this study is not without limitations. First, the research was conducted within a single institutional context in Iran, which may limit the generalizability of the findings to other educational settings or cultural backgrounds. Future studies should consider replicating this research across diverse contexts to examine the cross-cultural applicability of GenAI tools in L2 writing instruction. Second, although the use of the LGCM approach enabled the tracking of developmental trajectories, the study relied solely on quantitative data. Incorporating qualitative methods, such as interviews, learner diaries, or think-aloud protocols, could provide deeper insights into learners' cognitive development and affective responses. Additionally, the study focused exclusively on one GenAI platform (Gemini), and thus does not account for potential differences in learner outcomes based on the specific features of other GenAI systems. Comparative studies evaluating multiple GenAI tools (e.g., ChatGPT, Claude, Gemini) would offer a broader understanding of how different technologies shape L2 learners' writing development and writing anxiety.

Conclusion and Implications

This longitudinal study aimed to examine the progression of L2 learners' writing proficiency and anxiety throughout an academic writing course, while also assessing the influence of Gemini on these developmental patterns. Employing the LGCM approach, the study found that learners who engaged with Gemini showed significant improvements in writing performance and a notable reduction in writing-related anxiety. These results highlight the dual potential of GenAI tools in fostering cognitive growth and supporting emotional well-being in L2 writing contexts. By providing adaptive and individualized feedback, Gemini appears to have facilitated both skill development and anxiety reduction, enabling learners to engage more confidently with complex L2 writing tasks.

Theoretically, this study advances our understanding of how GenAI tools can serve as effective mediational resources in L2 learning, extending sociocultural perspectives on language development. By providing adaptive, personalized support, GenAI platforms like Gemini embody the principles of scaffolding within the ZPD, facilitating learners' gradual internalization of complex writing skills. This underscores the evolving role of technology not merely as a tool but as an interactive agent that actively shapes both cognitive and affective dimensions of language acquisition. Practically, the findings underscore the transformative potential of integrating GenAI technologies into L2 writing pedagogy. L2 teachers can leverage tools such as Gemini to provide personalized, real-time feedback on grammar, vocabulary, and structure, helping learners refine their writing through iterative practice. This tailored support can enhance learners' writing proficiency and reduce their writing-related anxiety by creating a low-stress, nonjudgmental environment where learners feel more confident experimenting with language. To maximize these benefits, instructors are encouraged to integrate GenAI tools systematically throughout the writing process—from brainstorming and outlining to revising and editing—while also guiding students on how to use these tools ethically and effectively. For curriculum developers, the results point to the importance of embedding GenAI tools like Gemini into the structure of L2 writing programs. This includes designing activities that explicitly incorporate GenAI-supported writing tasks, offering learners structured opportunities to benefit from AI feedback while maintaining human oversight. Such integration should be aligned with instructional goals and developmental stages to ensure that technology serves as a scaffold rather than a substitute for learning.

Authors contribution Both authors contributed to all stages of this paper.

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

Declarations

Conflict of Interest The authors declare that they have no competing interests.

Ethical Approval All procedures performed in the study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Consent to Participate Informed consent to participate was obtained from all individual participants included in the study.

Consent for Publication Informed consent for publication was obtained from all individual participants included in the study.

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