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Technology Integration in Chinese Literacy Instruction: A Mixed-Method Study of In-service Teachers[1]

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Abstract

This study explores how the Digital Divide shaped Taiwanese elementary-school Chinese teachers' technology-assisted literacy instruction before, during, and after the COVID-19 pandemic. Guided by Bronfenbrenner's Ecological Systems Theory, this mixed-methods study used mixed-effects modeling and thematic analysis. Quantitative findings show increased post-pandemic technology use, with teaching experience and professional development predicting adoption. Qualitative data reveal barriers such as device limitations, misaligned training, and technology's dual role as aid and distraction. The study highlights how macrosystem, exosystem, and chronosystem factors influence instructional practices and teacher growth. Findings suggest the need for sustained, context-sensitive professional development, pedagogically appropriate tools, and attention to region-specific inequities. This research offers a dynamic framework for understanding technology integration in non-Western literacy education.

Introduction

Technology integration in literacy instruction has emerged as a cornerstone of contemporary education, enhancing the delivery of instruction and student engagement with learning materials. The literature underscores a generally positive reception toward technology in literacy instruction (Hutchison & Reinking, 2011; Mudra, 2020; Sardegna & Yu, 2015). Technologies have been instrumental across various facets of literacy, including emergent literacy, fluency, vocabulary, reading comprehension, and writing (Baker, 2017; Huang, 2015; Hong & Lee, 2023; Lange, 2019; Lee et al., 2022; Roberts-Tyler et al., 2023).

Despite the promising benefits, integrating technology in literacy instruction is challenging. Most technology used in literacy instruction is designed to be motivational and multimodal, but often lacks grounding in robust theoretical models. It relies heavily on cognitive frameworks while overlooking critical sociocultural perspectives (Yang et al., 2018; Yang et al., 2021). Moreover, the Digital Divide, a phenomenon marked by unequal access to technology, varied usage patterns, and differing outcomes, has significantly complicated the integration of technology into literacy instruction. Due to the phenomenon of Digital Divide, teachers, especially those who work in the communities with diverse socioeconomic (SES) backgrounds, may encourage or limit the use of technology based on factors such as the availability of resources, access to training and support, and personal attributes like their attitudes, confidence, and beliefs about technology (Bećirović, 2023; Castells & Cardoso, 2006; Johnson et al., 2016; Salinas & Sanchez, 2009).

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High-quality teacher professional development can narrow the Digital Divide by enhancing teachers' knowledge and skills. Professional development (PD) also enables teachers to navigate the rapidly evolving environment of technology-assisted instruction (Borko, 2004). Nevertheless, closing this gap depends not only on training and tools but also on teachers' psychological readiness. Without the confidence and competence to implement technology meaningfully, even the teachers with abundant resources may fail to deliver effective literacy instruction (Klassen & Tze, 2014). Moreover, technology integration is formed by how teachers interpret curricula and apply instructional strategies, which is mainly attributed to individual beliefs. Teachers with more experience in implementing technology tend to deliver more effective literacy instruction (Fahrman et al., 2020). Therefore, exploring how PD, teaching experience, and teachers' attitudes toward technology is necessary, as it provides valuable information for translating theories into effective literacy instructions.

While significant research has examined the use of instructional technology in literacy instruction for English teachers in English-speaking countries, little attention has been paid to the implementation of instructional technology by Chinese teachers in Chinese-speaking countries. This lack of attention is particularly noteworthy considering that Chinese, a language marked by significant visual complexity and requiring a more extended period of time to establish basic literacy skills (Kuo et al., 2014; 2024; Perfetti, 2003), stands to benefit greatly from technological enhancements. The COVID-19 pandemic, which forced an abrupt shift to online teaching, has further highlighted the need to understand how such disruptions affect teachers' learning and PD. Moreover, exploration is required to understand how the Digital Divide affects teachers' decisions regarding technology integration. Therefore, in the present study, we aim to investigate the professional growth trajectory of the Chinese teachers in Taiwanese elementary schools[2] in technology-assisted literacy instruction during the pandemic era, and how the factors of the Digital Divide influence their growth.

Taiwan provides a unique and valuable context to serve the purpose of the present study due to its strong national commitment to digital education. The Ministry of Education has implemented several initiatives, such as the "Smart Education Policy" and "Future Classroom Development Program," to promote technology use in K–12 education (Ministry of Education, 2021). Besides, most schools in Taiwan have the access to the internet and digital devices, making it a suitable context for research (Chen et al., 2020). This investigation will offer crucial insights into the unique challenges and opportunities for technology integration in non-Western linguistic contexts, thereby informing future policy development and refining instructional practices for literacy education in similar language and cultural settings.

Theoretical Framework

Digital Divide

The Digital Divide, a phenomenon first outlined by Van Dijk (2005), is a model characterized by three levels. The first level concerns unequal access to digital devices and internet connectivity. The second level addresses disparities in technology use, including variations in frequency, purpose, and digital skills. The third level highlights differences in individuals' benefits from technology use, such as academic success, employment opportunities, or social participation. This model has been supported and extended by Wei et al. (2011), confirming that access (the first

[2] In the context of Taiwan, "elementary teachers" refers to those teaching students in Grades 1 through 6, typically ages 6 to 12.

level) alone does not guarantee meaningful or effective technology use, indicating the value of teacher PD in the second and third levels.

The Ecological Systems

Investigating the growth trajectory of Chinese teachers' use of technology and its relationship with the Digital Divide requires a multifaceted approach that goes beyond linear cause-and-effect models. Traditionally, research on teacher PD has primarily focused on the direct effect of the PD interventions, often overlooking the teacher learning process and the formation of instructional beliefs (Goldsmith et al., 2014; Opfer & Pedder, 2011). Ehrenfeld (2022) proposed a theoretical framework that conceptualizes teachers' PD as a complex and dynamic process to bridge this gap. Based on Bronfenbrenner's (1979) Ecological Theories, which explain that human development is influenced by different layers of environmental systems, Ehrenfeld (2022) operationalized this lens to identify and distinguish the levels and contexts in which teacher learning occurs.

The traditional Ecological Theories proposed five interrelated systems in a person's developmental environment (Bronfenbrenner, 1979): microsystem, mesosystem, exosystem, macrosystem, and chronosystem. The microsystem refers to the immediate environment in which an individual directly interacts, such as classrooms, families, and peer groups. The mesosystem encompasses the interconnections between these microsystems. For example, how school and home experiences influence each other. The exosystem includes broader social settings that indirectly affect the individual, such as school district policies or parental work environments. The macrosystem comprises the cultural values, societal norms, and ideologies that shape all other systems. Finally, the chronosystem accounts for the dimension of time, recognizing that both individual development and environmental contexts change over time.

Ehrenfeld (2022) further applied Bronfenbrenner's framework by mapping teacher learning across ecological levels. The microsystem focuses on immediate learning settings, including PD sessions and teacher reflections. The mesosystem encompasses institutional contexts, such as classroom practices and school structures. The macrosystem reflects larger societal forces, including cultural, economic, and policy contexts that shape the environment in which teachers learn and teach. The exosystem captures broader professional settings indirectly influencing learning, such as previous schools, professional development workshops, or professional communities. Finally, the chronosystem captures the time dimension, accounting for how teachers' learning and instructional contexts evolve across key transitions and historical events.

The present study adopts Ehrenfeld's (2022) concept of scope within Bronfenbrenner's (1979) Ecological Systems Theory to examine how Chinese teachers in Taiwan use technology in their literacy instruction. Bronfenbrenner's theory posits that an individual's development is deeply influenced by a series of interconnected environmental systems. Our study specifically draws on the assumption that teacher professional growth in technology integration is not solely an individual endeavor, but is profoundly shaped by the complex interplay of their immediate and broader ecological contexts.

Building on this, Ehrenfeld's (2022) concept of scope, which emphasizes recognizing and distinguishing the various salient contexts influencing teacher learning and professional development, allows us to analyze how these multi-level factors contribute to teachers' professional growth. Specifically, we explore aspects of the Digital Divide as shaped by factors in the macrosystem (school SES), exosystem (teaching and professional development experiences), and chronosystem (policy reforms due to the COVID-19 pandemic), as well as the specific concerns and instructional needs expressed by teachers in the context of literacy instruction.

Within the context of the pandemic chronosystem, we anticipated that Chinese teachers' interpretation and implementation of government-issued digital policies would be influenced by multiple ecological levels. These dynamic interactions were expected to intricately shape their use of technology in literacy instruction. For instance, do schools with varying socioeconomic statuses provide equitable access to digital resources? Does teachers' prior experience facilitate or impede their integration of technology? Is sufficient PD available to support technology-enhanced instruction, and how effective are these PD programs? Moreover, how do interactions across these ecological levels contribute, either directly or indirectly, to the digital divide in Taiwanese literacy education?

This dual theoretical lens directly guided our research design. The survey instrument was developed to capture teachers' experiences and perceptions across these identified ecological levels, with specific sections addressing questions related to school resources (macrosystem), access to and participation in PD (exosystem), and the impact of pandemic-related changes (chronosystem). Furthermore, items were included to ascertain teachers' specific literacy instruction practices and perceived needs. Our analysis of the results will explicitly examine the relationships between these ecological factors and teachers' reported professional growth and technology integration decisions, allowing us to understand how different contextual "scopes" influence teachers' technology use in a complex, interconnected manner, beyond a simple cause-and-effect relationship.

Empirical Literature Review

This section reviews empirical studies that examine how our focused ecological factors contribute to the Digital Divide in the context of technology integration education, particularly in literacy instruction. Specifically, the review is organized around three levels of Bronfenbrenner's ecological theory: the macrosystem (SES), exosystem (teaching and PD experiences), and chronosystem (COVID-19 pandemic).

The Macrosystem – SES and Digital Divide

The SES of schools affects access to technology and shapes teachers' attitudes, instructional goals, and decisions about how technology is used in the classroom. Reinhart et al. (2011) examined differences in K–12 educators' use of technology across schools with varying economic backgrounds, analyzing survey data from 94 in-service teachers. The findings supported the presence of the Digital Divide across all three levels concerning school SES. Ritzhaupt et al. (2013) investigated Information and Communication Technology (ICT) literacy among Florida middle school students by SES, ethnicity, and gender. Their results revealed significant SES-based disparities, particularly in teacher usage and pedagogy, emphasizing the need to move beyond hardware provision toward meaningful technology integration. Head et al. (2023) explored how scalable, technology-based professional development supports early literacy instruction in low-resource Kenyan primary schools. Despite challenges related to access, their findings suggest that well-designed PD can help reduce second-level divides.

In terms of decision making, Natriello (2001) suggested that teachers in schools with high SES contexts tend to have the attitude and profession to use technology to facilitate students' higher-level thinking. In contrast, teachers in schools with lower SES contexts limit the use of technology to drills and operational chores. Similarly, Graves and Bowers (2018) conducted a latent class analysis using a nationally representative sample of 2,764 public school teachers from the NCES FRSS 2009 dataset to identify typologies of technology-using teachers. They found that low-SES

school teachers were more likely to use technology in limited, procedural ways, such as basic skill drills. In contrast, teachers in high-SES contexts were more likely to adopt versatile and pedagogically integrated technology uses. Together, these studies demonstrate that SES is a significant indicator, not only influencing access to technology but also shaping how it is utilized.

The Exosystem – Teaching Experiences and Digital Divide

Besides SES, teachers' experience and attitude play a key role in providing access to the digital world and helping to reduce the Digital Divide, particularly at the second level (Barzilai-Nahon, 2006). Van Braak et al. (2004) surveyed 468 teachers working in primary education in the Dutch-speaking region of Belgium on the technology used in teaching, showing that less than half of the participants incorporated technology as a means to facilitate students' cognitive construction in their instructional moves, which can be attributed to teachers' limited technology experience and insufficient support from the school. Han et al. (2017) examined how student teaching experiences influence pre-service teachers' self-efficacy and intention to use technology, highlighting the role of teaching experience in shaping future instructional practices. Their study of 55 South Korean pre-service teachers found that practicum experiences significantly improved participants' confidence in technology use. The finding is relevant to the second-level Digital Divide, suggesting that the absence of early structured teaching experiences and belief-sensitive training, especially those with limited confidence or more traditional views, may adopt superficial uses of technology that do little to enhance instruction. This way, differences in teaching experiences and beliefs can contribute to unequal classroom technology use, even when access is not a barrier.

Studies have shown that when technology is used responsibly and strategically by instructors, it can significantly enhance literacy instruction, increasing student motivation and enabling more personalized educational experiences (Hutchison & Reinking, 2011). However, this is often based on the foundation of teachers' prior knowledge and teaching experience. Huang (2015) investigated the impact of technology on the vocabulary development of second-grade students in a public elementary school in the southeastern United States. The study involved 40 students from two classes, one assigned to an experimental group and the other to a control group. The teacher of the experimental group received training to implement E-PowerPoint strategies, which incorporated rhymes, sample sentences, and animated stories with voiceovers to reinforce sight words. Students in this group demonstrated significantly greater engagement and post-test vocabulary improvement than those in the control group, who received traditional instruction without technology integration. Milton and Vozzo (2013) examined how pre-service aboriginal teachers in Australia developed digital literacy and pedagogical strategies for literacy instruction through structured practicum experiences. Nineteen third- and fourth-year education students participated in two teaching placements (one remote and one urban), where they implemented technology-supported literacy activities such as digital storytelling, PowerPoint recounts, and YouTube-supported writing tasks. While many began with limited confidence and experience in using digital tools, their skills improved through reflection, feedback, and school-based practice. The findings from the aforementioned studies illustrate how teacher preparation programs and field experiences can help close the second-level Digital Divide by building teachers' capacity to use technology meaningfully in literacy instruction, especially in under-resourced or remote educational settings.

The Exosystem – PD Experiences and Digital Divide

As mentioned above, a well-designed PD targeted at training in technology integration can effectively close the gap in the digital divide. Regardless of the initial inequity in resource access and internet connectivity, PD provides pre-service and in-service teachers with opportunities to reevaluate their ongoing technology implementation and helps them identify the challenges they face in real teaching sites. In Christ et al. (2019), the researchers drew on data from 44 junior-level education majors enrolled in a literacy methods course in a U.S. university, examining the challenges and successes preservice teachers encountered while integrating technology into literacy instruction. Findings revealed that many pre-service teachers struggled to align technology choices with instructional goals, manage student engagement, and use digital tools effectively. Nonetheless, through ongoing reflection, collaborative analysis, and structured practicum experiences, participants showed growth in their ability to integrate technology meaningfully into literacy instruction. Similarly, in Snell et al. (2019), the researchers reviewed how Tech PD supports early childhood educators in literacy instruction, finding it effective, particularly with in-person components, but also highlighting challenges such as teacher tech readiness and infrastructure costs.

As a result, effective PD assists teachers in integrating their content and technology knowledge. Mishra and Koehler (2006), proposed the Technological Pedagogical Content Knowledge (TPACK) framework from the extension of Shulman's (1986) concept of Pedagogical Content Knowledge (PCK), emphasizing that effective technology integration in teaching requires a dynamic interplay among three core domains: content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK). Beyond knowing each domain in isolation, teachers must also develop integrated knowledge at the intersections, pedagogical content knowledge (PCK), technological content knowledge (TCK), and technological pedagogical knowledge (TPK), culminating in the synthesized knowledge base of TPACK. This framework offers a valuable guide for designing high-quality professional development programs that prepare teachers to use technology purposefully and effectively in their instructional practice.

Several studies focus on the PD of teachers' Technological Pedagogical Content Knowledge (TPACK) development. Voogt and McKenney (2017) investigated whether Dutch teacher education institutes effectively prepare pre-service teachers to integrate technology into early literacy instruction. Their findings revealed that teacher educators often lacked dual expertise in both literacy and technology, resulting in fragmented curricula and limited support for developing integrated TPACK. In Chinese literacy studies, Cheng (2017) surveyed 172 in-service Hakka language (a Chinese dialect) teachers' perceptions of TPACK in Taiwan. The results revealed that the Hakka language teachers were generally satisfied with their TPACK but showed lower confidence in CK, TK, and TPK. More recently, Qiu et al. (2022) examined the TPACK framework among 286 pre-service teachers of Chinese as a second language in China. The results showed that teachers struggled to differentiate TPK, TCK, and synthesized TPACK. The study also found that the teachers were slightly satisfied with their overall TPACK but were least confident of their TK. These studies underscore the importance of integrated technological expertise in teacher training and highlight professional development as a key factor in shaping teachers' technology learning trajectories.

The Chronosystem – COVID-19 Pandemic & Digital Divide

The COVID-19 pandemic has accelerated the adoption of digital tools for classroom instruction (Alajmi, 2022; Winter et al., 2021), as reflected in a study involving U.S. elementary

teachers who shared their experiences and insights on technology's evolving role in education (Eutsler et al., 2023). Moreover, the pandemic has profoundly impacted education systems worldwide, and Taiwan was no exception. Amidst the escalating COVID-19 cases in May 2021, the Taiwanese government decided to close all schools, following a survey that showed an overwhelming 91.6% approval for the closures (Chao et al., 2022). This shift necessitated a rapid adaptation to online learning, particularly in teaching Chinese literacy. Elementary school teachers in Taiwan, who had been receiving an increasing supply of technology equipment and training since the late 1990s (Sardegna & Yu, 2015), were suddenly thrust into a situation where their ability to utilize instructional technology was crucial. Additionally, after the pandemic, the emergences of new challenges, such as students' engagement and digital fatigue, the balancing of the integration of technology with existing curriculum, and the existing ones, such as insufficient training and support, and the discrepancy of the students' access to technology in different SES setting, make some teachers shifted back to offline teaching (Christopoulos & Sprangers, 2021; Compagnoni, 2023; Patni & Wardani, 2024). Therefore, examining how the COVID-19 pandemic, as part of the chronosystem, has either positive or negative effects on the teachers' integration of techno ledge is essential for informing future educational policy and practice.

The Present Study

While extensive research has been conducted on applying instructional technology for literacy instruction among English teachers, only a handful of studies have focused on literacy instruction for Chinese teachers. Given that Chinese has a writing system of exceptional visual complexity and takes longer to acquire (A, 2014; A, 2024; Perfetti, 2003), understanding how Chinese teachers adapt to and adopt instructional technology offers unique insights that differ from those found in research on English teachers. To our knowledge, no study has examined how recently in-service teachers have used developed instructional technology to enhance Chinese literacy acquisition with ecological theories and the Digital Divide framework. Therefore, this study addresses this gap by examining the use of instructional technology by in-service Chinese language teachers in Taiwan. Our research questions are listed as follows:

1. How did the use of technology-integrated activities in Chinese literacy classrooms differ before, during, and after the pandemic across schools with varying socioeconomic contexts, considering in-service teachers' experience levels and participation in professional development programs?
2. How did the use of technology equipment in Chinese literacy instruction differ before and after the pandemic across schools with varying socioeconomic contexts, considering in-service teachers' levels of teaching experience and their participation in professional development programs?
3. What challenges did in-service teachers encounter in integrating technology into Chinese literacy instruction, and how did these challenges vary by school context, experience level, and professional development access that may potentially lead to Digital Divide?

Method

Context and Participants

The participants for this study were in-service Chinese language teachers residing in Taiwan. In Taiwan, Chinese serves as an official language and is the foundational language of instruction across the K–12 curriculum, where it is a compulsory subject annually. The recruitment aimed for a diverse sample, encompassing a range of ages, genders, teaching experiences, geographical locations, and schools serving students from various socioeconomic backgrounds, ensuring a comprehensive representation of the teaching context.

Research Design

Drawing upon Bronfenbrenner's (1997) ecological systems theory and its application to teachers' PD (Ehrenfeld, 2022), this study explored the intricate relationships among the exosystem, the macrosystem, and the chronosystem using an explanatory sequential design mixed-method design (Creswell & Clark, 2017). Mixed-methods approach (Creswell & Clark, 2017) was selected not only for its demonstrated utility in investigating complex and multifaceted relationships, but also because it is a frequently utilized and well-established design in existing studies drawing upon Bronfenbrenner's (1997) ecological systems theory (e.g., Lodato, 2024; Mahmud, 2022; Xie et al., 2024). The measures included: a) a nationwide online survey of in-service teachers, and b) several focus group interviews.

Measures

Survey. A survey was developed by an expert team to address our main research questions and capture variables at each level of Bronfenbrenner's (1979) ecological systems theory, as presented in the literature review. This team comprised: a) two faculty members specializing in Chinese literacy instruction and computer-assisted language learning; b) two graduate students with expertise in research methodology and measurement; and c) one experienced Chinese language teacher in Taiwan, who had taught throughout the pandemic. This diverse team ensured the development of a robust survey capable of capturing the complex relationships central to this study. The survey was piloted with two additional Chinese language teachers who were also graduate students and had pandemic teaching experience. Based on feedback from the pilot study, revisions were implemented, mainly involving rephrasing to enhance clarity.

The survey consists of three sections. The first section collected demographic information, including participants' gender, year of birth, teaching experience as elementary Chinese teachers, and geographical location of their schools to indicate the school SES. The study employs three indicators: urban, suburban, and remote. Based on the Urbanization Classification Index in Taiwan (Ministry of the Interior, 2024), the urban areas are the six special municipalities: Taipei, New Taipei, Taoyuan, Taichung, Tainan, and Kaohsiung. Suburban areas refer to the outskirts of the six special municipalities and the urban centers of general counties and cities. Remote areas refer to the outlying islands, mountainous regions, and townships with limited transportation access. The second section examined the types of participants' use of online platforms and technology equipment in their teaching practices before, during, and after the COVID-19 pandemic. The third section examined the frequency of participants' involvement in professional development programs related to technology-assisted instruction.

The survey was conducted in Taiwan, involving 111 participants (F = 80, M = 31), who were elementary in-service Chinese teachers. A stratified sample of schools representing different SES

levels across Taiwan's cities and encompassing all elementary grade levels was achieved through strategic engagement with professional networks and associations. Key organizations, such as city-level principals' associations and elementary school teacher unions in cities associated with distinct SES levels, were contacted. Due to data protection guidelines, we could not access the total number of prospective participants reached, making it impossible to calculate a precise response rate. Participant recruitment concluded once a diverse group of participants was secured and the allocated recruitment period for the study ended. The study's need for school participation from these specific urban areas facilitated the recruitment of a sample inherently reflecting the intended SES stratification. These networks then disseminated recruitment information to elementary schools within their respective cities, ensuring representation across all grade levels within those targeted urban areas.

Interview. The semi-structured interview questions were developed by the same expert team responsible for the survey design. They were structured to explore variables at each level of Bronfenbrenner's (1979) ecological systems theory, as presented in the literature review, and to directly address our main research questions. While paralleling the overall structure of the survey, the interviews focused on eliciting open-ended responses and rich experiential data that could not be captured quantitatively.

The interview questions were specifically crafted to delve into the context, challenges, opportunities, personal reflections, and suggestions of the participants, providing a qualitative depth to the quantitative findings. Each question was designed to explore how the various ecological levels (microsystem, mesosystem, exosystem, macrosystem, chronosystem) influenced teachers' experiences, directly informing our research questions by offering nuanced insights into the complex interactions within the system.

As with the survey, the interview protocol underwent a pilot study with two additional Chinese language teachers. These teachers were also graduate students and had direct experience teaching during the pandemic. Based on their valuable feedback, revisions were implemented, primarily involving rephrasing to enhance clarity and ensure the questions effectively elicited the desired in-depth information.

Four participants voluntarily participated in a follow-up interview, during which they were asked to share their beliefs about technology-assisted instruction and their technology use following the pandemic.

Data Analysis

Quantitative Data

Variable coding and grouping. Variables were coded to capture information relevant to each level of Bronfenbrenner's ecological systems theory. The microsystem and mesosystem levels were primarily captured through direct survey items related to teachers' immediate classroom experiences and interactions, as detailed in Table 1. The *exosystem variable*, teaching experience, was captured on a five-point ordinal scale (1 = less than 2 years to 5 = more than 20 years), reflecting the impact of broader institutional and professional contexts on teachers. Another *exosystem variable,* PD, was measured using seven topic-specific items (e.g., reading instruction, educational technology). Each item was coded as 1 ("participated") or 0 ("not participated"), and these were summed to create a total PD score (range = 0–7), indicating the breadth of a teacher's engagement with professional growth opportunities. The *macrosystem variable*, school SES, was categorized based on geographic location (1 = remote, 2 = suburban, 3 = urban). This grouping

reflects the broader societal and cultural influences on the school environment. ***The chronosystem, a key focus of the present study, was operationalized through data collected at three distinct time points: pre-pandemic, during-pandemic, and post-pandemic. This allows us to analyze the impact of changes over time.***

Two primary outcome variables captured different facets of technology integration: a) Number of equipment types used for each time point (pre-, during-, and post-pandemic), each specific equipment type was coded as 1 ("used") or 0 ("not used") and then summed to reflect the diversity of tools employed; and b) Number of instructional activities incorporating technology: Similarly, for each time point, each relevant activity type was coded as 1 ("used") or 0 ("not used") and summed to indicate the diversity of technology-infused instructional practices.

This systematic coding and grouping of variables directly informs our research questions by allowing us to analyze changes and relationships across different ecological levels and over time, providing a robust empirical base for understanding the transformation of Chinese literacy instruction.

Statistical modeling. Mixed-effects models were employed to examine trends in technology use in Chinese literacy instruction across pre-, during-, and post-COVID-19 periods with the alignment of Bronfenbrenner's ecological systems theory. Mixed-effects models are a powerful statistical approach particularly suitable for analyzing data with repeated measurements taken from the same units and offers several key advantages over traditional regression methods, such as handling of unbalanced data and missing values, increased statistical power and generalizability (Bryk & Raudenbush, 1992; Fitzmaurice et al., 2011). The analysis specifically investigated changes in 1) technology-enhanced activities: class activities involving technology; and 2) technology equipment: the technology equipment utilized in the classroom. For both outcomes, usage frequencies were converted into binary values (1 = used, 0 = unused), then summed to calculate the total number of distinct types employed at each time point (pre-, during-, post-pandemic), emphasizing diversity of use. All analyses were conducted using STATA 18. Controlling for age and gender, the mixed-effects models included key predictors aligned with Bronfenbrenner's ecological systems theory: school socioeconomic status (SES; macrosystem), teaching experience and recent participation in professional development (2018–2023; exosystem), and time (categorized as pre-, during-, and post-pandemic; chronosystem). Interaction terms between time and each predictor were included to examine whether the effects of these ecological factors varied across different phases of the pandemic.

School SES was operationalized using school geographical location, categorized into three levels, remote, suburban, and urban, as a proxy for structural socioeconomic context. Although school SES is conceptually a school-level variable, we treated it as a teacher-level covariate due to the low teacher-to-school ratio and the absence of school identifiers. As a result, there was no need to model school-level clustering explicitly. Thus, a two-level model, with time points nested within teachers, was the most appropriate structure given the data.

In the activity model, random intercepts and random slopes for time were specified to capture individual (i.e., teacher-level) differences in baseline levels and change over time. For the equipment model, the variance component for the random slope was not statistically significant, and model fit indices (AIC and BIC) indicated a better fit for a simpler specification. Consequently, a random-intercept-only model was adopted for the equipment outcome. All models were estimated using maximum likelihood (ML) estimation.

Qualitative data. To develop themes that offer a deeper understanding of our research questions within the lens of Bronfenbrenner's (1979) ecological systems theory, we adopted thematic analysis (Clarke & Braun, 2017) for the interview data. Our approach incorporated an innovative AI-assisted coding procedure, which is an emerging and legitimate method in qualitative research using large language models (LLMs). Studies have demonstrated that, with human validation, AI can efficiently process large volumes of text to identify descriptive themes and patterns in interview data (Joel-Edgar & Pan, 2024; Lee et al., 2024; Morgan, 2023).

Coding and classification of interview data. Our coding and classification process was designed to illuminate insights directly relevant to each level of Bronfenbrenner's framework:

1. Translation and Initial Review. The original interview transcripts were first translated from Chinese to English using ChatGPT-4o. This initial step ensured accessibility for the broader research team. Subsequently, two well-trained research assistants manually reviewed these translated transcripts. Their role was critical in identifying preliminary themes which served as initial coding tags. These preliminary themes were often broad and allowed for an initial categorization of teacher experiences related to changes in their macrosystem (SES), and exosystem (e.g., teaching experience, professional development) and chronosystem (e.g., impact of pandemic),
2. AI-Assisted Thematic Analysis. Once these general themes were established, the transcripts and corresponding coding tags were uploaded to two distinct AI tools: ChatGPT-4o and Microsoft Copilot. This allowed for a more comprehensive and systematic thematic analysis, where the AI tools processed the text to identify recurring patterns and refine thematic categories. The use of two AI platforms enabled us to assess inter-rater reliability (IRR) by comparing the consistency and alignment of theme tagging across both tools. The research assistants then rigorously assessed the coding reliability between the AI tools based on the accuracy and relevance of the tags. This dual AI approach, followed by human validation, efficiently generated a robust set of descriptive themes reflecting the nuances of the data. Themes related to influences from macrosystem (SES), exosystem (e.g., teaching experience, professional development) and chronosystem (e.g., pandemic influence) were specifically sought and refined during this stage, and
3. Human-Validated Interpretive Analysis. Following the AI-generated and human-validated descriptive themes, a more nuanced and interpretive analysis was conducted by the human researchers. This stage involved moving beyond mere description to interpret the meaning and implications of the themes, explicitly linking them back to the complex interactions hypothesized within Bronfenbrenner's ecological systems theory and how they answer our research questions. This ensured that the identified themes were not just patterns, but conceptually rich insights.

Triangulation of themes for deeper insights. To gain deeper insights into each of our research questions, we employed triangulation by systematically comparing and integrating the themes derived from the interview analysis with the findings from the survey data.

1. Complementary Perspectives. The qualitative themes provided rich, contextual details and personal narratives that *explained the "why" and "how"* behind the quantitative patterns observed in the survey. For instance, if the survey indicated a change in technology use (chronosystem/outcome variable), the interviews revealed the macrosystem (SES) and

exosystem (e.g., teaching experience, professional development) that contributed to variations in this change,

2. Convergent and Divergent Findings. We looked for areas where quantitative results and qualitative themes converged, strengthening the validity of our findings. For example, if the survey showed an increase in professional development (exosystem variable), interview themes might detail the specific types of effective (or ineffective) PD and their macrosystem influences, providing a richer understanding. Conversely, divergent findings were explored as opportunities for deeper inquiry, prompting further reflection on the multifaceted nature of the ecological system's impact, and
3. Holistic Understanding: This triangulation allowed us to move beyond isolated findings to build a holistic understanding of the transformation of Chinese literacy instruction. By connecting teachers' reported experiences (qualitative themes) to the broader statistical trends and specific ecological factors (quantitative survey data), we could construct a more comprehensive narrative that directly addressed each of our research questions, ultimately explaining the complex interplay of the ecological system levels in shaping teachers' pedagogical adaptations during the pandemic.

Results & Discussion

With the scope of the Ecological Systems (Bronfenbrenner, 1979) in teachers' professional development (Ehrenfeld, 2022), our findings offer a multifaceted insight into the integration of educational technology into Chinese literacy instruction, particularly in the context of the COVID-19 pandemic. Quantitative and qualitative data were examined with the macrosystem (SES), the exosystem (teachers' teaching and PD experience), and the chronosystem (COVID-19 policy change) to elucidate the phenomenon of Digital Divide (Van Dijk, 2005).

Our quantitative results highlight the ongoing technology use and access discrepancy across different school SES locations. Table 1 presents the descriptive statistics for the variables of interest. The mean teaching experience (TE) of the teachers was 3.8 years, ranging from 1 to 5 years. The mean frequency of PD that the teachers had participated in the last five years was 4.92, with a maximum frequency of 7. The SES distribution of the teachers' school location was 23% in remote areas, 27% in suburban areas, and 50% in urban areas. The mean number of equipment types used pre-pandemic was 4.68 (max = 20), increasing to 13.5 post-pandemic (range = 2–25). For technology in activities, the pre-pandemic mean was 4.01 (max = 22), rising to 17.88 during the pandemic (range = 3–26) and 16.9 post-pandemic (max = 26).

Table 1.

Descriptive Statistics

Variable	M	SD	Min	Max	N
Age	44.31	9.7	25	63	112
Teaching Experience (TE)	3.8	1.26	1	5	112
Professional Development (PD)	4.92	1.72	0	7	112
Equipment - Pre-pandemic (E-Pr)	4.68	3.69	0	20	106
Equipment - Post-Pandemic (E-Po)	13.5	4.2	2	25	112
Activity - Pre-pandemic (A-Pr)	4.01	4.5	0	22	96
Activity - During pandemic (A-D)	17.88	5.41	3	26	112
Activity - Post-pandemic (A-Po)	16.9	6.6	0	26	112
Gender					111
Male	31 (27.93%)				
Female	80 (72.07%)				
SES					112
Remote (1)	26 (23.21%)				
Suburban (2)	30 (26.79%)				
Urban (3)	56 (50.00%)				

A Pearson correlation analysis examined the relationship between the continuous variables (see Table 2). The results showed that age had a strong positive correlation with TE, $r(110)=.9$, $p<.01$, strong negative correlations with E-Po, $r(110)=-.36$, $p<.01$, and A-Po, $r(110)=-.27$, $p<.01$, and had a moderate negative correlation with A-Pr, $r(94)=-.24$, $p<.05$.TE had a strong negative correlation with E-Po, $r(110)=-.25$, $p<.01$, and a moderate negative correlation with A-Po, $r(110)=.22$, $p<.05$. PD had moderate positive correlations with E-Po, $r(110)=.21$, $p<.05$ and A-D, $r(110)=.2$, $p<.05$. E-Pr had a moderate positive correlation with E-Po, $r(110)=.23$, $p<.05$. E-Po had strong positive correlations with A-D, $r(110)=.43$, $p<.01$ and A-Po, $r(110)=.48$, $p<.01$. A-Pr had a moderate positive correlation with A-D, $r(110)=.2$, $p<.05$, and A-D had a strong positive relationship with A-Po, $r(110)=.63$, $p<.01$. These findings indicate that age and TE are strongly associated with technology integration patterns, with older teachers showing greater TE but reporting less equipment use and fewer tech-integrated activities, particularly post-pandemic. In contrast, greater PD participation was positively correlated with increased equipment use post-pandemic (E-Po) and activities during the pandemic (A-D), suggesting that PD played a key role in supporting instructional adaptation. Although the pandemic has accelerated the adoption of digital tools in Chinese classrooms, the degree of implementation varied based on teacher-related factors and school SES contexts.

Table 2.

Correlation

	Age	TE	PD	E-Pr	E-Po	A-Pr	A-D	A-Po
Age	-							
TE	.9**	-						
PD	-.09	-.04	-					
E-Pr	-.15	-.08	-.05	-				
E-Po	-.36**	-.25**	.21*	.23*	-			
A-Pr	-.24*	-.17	-.08	.82	.22	-		
A-D	-.16	-.12	.2*	-.02	.43**	.2*	-	
A-Po	-.27**	-.22*	.09	.09	.48**	.19	.63**	-

Note. $p < .05$ (*), $p < .01$ (**).

As for qualitative data, five major themes were identified through manual coding from our interview data, including Educational Technology, the impact of the Pandemic, Reading Habits, Student Performance and Engagement, and Writing Challenges. The output of ChatGPT 4.0 and Microsoft Copilot was checked for their accuracy and relevance to the manual coding. The results are summarized in Table 3. It can be seen that the coding results were relatively accurate and relevant to the manual tags, and they further provided the subthemes and more detailed descriptions. Three subthemes emerged within the Educational Technology theme: teacher autonomy and professional growth, the inequality and usability of technology resources, and technology—supportive yet distracting. Similarly, the two new subthemes under Writing Challenges are handwriting as a foundational skill and vocabulary challenges influenced by digital media. They offer deeper insight into how technology impacts Chinese literacy instruction.

Table 3.

Qualitative Results

Manual Tags	AI-Generated Themes	AI Explanation	Supporting Quotes (Excerpt)
Educational Technology	Teacher Autonomy and Professional Growth	Teachers with strong intrinsic motivation actively seek out training and integrate new tools, such as 雄筆順 (Hsiung Stroke Order), 教育生活家 (Education Life), and 因材網 (Taiwan Adaptive Learning Platform). Professional development and peer support influence tech adoption significantly.	1. Ms. Chen: 'I follow all major publishers' Facebook pages and join any workshop I can.' 2. Ms. Chen: 'I also attended Google and Apple teacher certification programs.'

Educational Technology	Tech Resources: Inequality and Usability	Access to technology varies by school. While some teachers had rich tech resources and training, others struggled with inappropriate devices or a lack of age-appropriate tools.	1. Ms. Lin: “Every student has a tablet... our school also hosts training workshops.” 2. Ms. Lin: “The tablets bought are not suitable for lower grades.”
Educational Technology	Technology: Supportive - Yet Distracting	Technology aids in collaborative writing, accessibility, and differentiation, but it also increases student distraction and over-reliance on digital tools. Concerns exist around the loss of handwriting practice and critical thinking.	1. Ms. Lin: “Edtech is a double-edged sword... useful but also distracting.” 2. Ms. Lin: “Voice input helps fluency but might hurt character form learning.”
Impact of the Pandemic	Influence of the COVID-19 Pandemic	The pandemic significantly altered teaching practices and student behavior. Teachers had to shift to online instruction, which changed their use of technology, expectations for student independence, and assessment strategies. Some changes persisted post-pandemic, while others reverted.	1. Ms. Lin: “During the pandemic, online teaching made it hard for students to focus.” 2. Ms. Chen: “We had to learn new edtech tools quickly during COVID, and we kept using them after returning to classrooms.” 3. Ms. Lin: “Students’ structure comprehension improved post-pandemic, likely due to online training”
Reading Habits	Limited Reading Habits and Cultural Capital	Many students, especially those from lower-SES or multicultural families, lack rich reading environments, resulting in weaker language structure, cultural references, and engagement with classical content like idioms or proverbs.	1. Ms. Huang: “Without reading support at home, children’s reading volume drops dramatically.” 2. Ms. Huang: “Students today don’t know idioms or famous quotes to use in writing.”
Student Performance and Engagement	Writing Motivation and Classroom Attitudes	Students are often impatient with structured writing processes, preferring shortcuts or quick completion over deep engagement. Motivation is further hindered by external rewards or a lack of meaningful writing contexts.	1. Ms. Chen: “This class is all about being fast, not following steps patiently.” 2. Ms. Chen: “Only a few students truly engage with writing.”
Writing Challenges	Handwriting as a Foundational Skill	Teachers emphasize handwriting, especially for younger learners, for character structure, memory, and fairness. However, some also adapt to students’ needs by allowing digital input.	1. Ms. Huang: “Stroke order is fundamental... each stroke has a name.” 2. Ms. Huang: “Handwriting is more fair—what about students who type slowly?”

Writing Challenges	Vocabulary Challenges and Digital Influence	Students lack sufficient vocabulary for formal writing, with increasing reliance on informal, digital sources. This is further complicated by the influence of mainland Chinese terms and reduced exposure to idioms and literary expressions.	1. Ms. Huang: "Students nowadays mostly learn vocabulary from the internet... very colloquial and not appropriate for writing." 2. Ms. Lin: "Students often use mainland Chinese terms, like using 'application' instead of 'APP'."

To provide a more nuanced and comprehensive understanding of teachers' learning trajectories, we conducted mixed-effects modeling and analyzed illustrative quotes from the identified qualitative themes. The following sections address our three research questions:

Research Question 1: How did the types of tech-integrated activities in Chinese literacy classrooms differ before, during, and after the pandemic across schools with varying socioeconomic contexts, considering in-service teachers' experience levels and participation in professional development programs?

The Mixed-Effects Model predicting technology use in class activities (see Table 4) revealed significant changes over time. Technology use in class activities increased significantly during (b=1.06, SE=2.72, p=.001) and after (b=1.69, SE=3.40, p<.001) the pandemic compared to pre-pandemic levels. A marginally significant interaction effect between time and SES was observed for the SES suburban group after the pandemic (b= -.46, SE= 1.98, p=.056), indicating a potential trend where the increase in activities over time was less pronounced for individuals in the SES suburban group compared to the reference group. Teachers with more professional development exhibited greater increases in technology use during the pandemic (b=-.2, SE=0.34, p=.005). Significant variability was observed among teachers in both the initial levels of technology use (σ2=12.95, SE=7.13) and the rate of change over time (σ2=6.38, SE=1.93).

Table 4.

Mixed-Effects Model Predicting Activity

Fixed-effects	**Unstandardized *b***	**Standardized *b***	**SE**	**z**	**p**
Time_during pandemic	8.80	1.06	2.72	3.24	<.01
Time_post pandemic	14.03	1.69	3.40	4.12	<.001
Age	-0.17	-.20	0.08	-2.12	<.05
Gender_female	0.17	.02	0.84	0.20	0.840
PD	-0.36	-.07	0.29	-1.26	0.207
TE	0.69	.01	0.66	1.04	0.300
SES_suburban	1.21	.15	1.28	0.95	0.343
SES_remote	-0.87	-.10	1.23	-0.70	0.482
Time_during pandemic#SES_suburban	-1.27	-.15	1.58	-0.80	0.422

Time_during pandemic#SES_remote	2.08	.25	1.46	1.43	0.154
Time_post pandemic#SES_suburban	-3.79	-.46	1.98	-1.91	0.056
Time_post pandemic#SES_remote	-0.33	-.04	1.81	-0.18	0.853
Time_during pandemic#PD	0.95	-.20	0.34	2.78	<.01
Time_post pandemic#PD	0.55	.11	0.42	1.31	0.191
Time_during pandemic#TE	-0.12	-.02	0.45	-0.26	0.794
Time_post pandemic#TE	-0.72	-.11	0.56	-1.28	0.199
_cons	10.76		2.83	3.80	<.001
Random-effects	**Variance**		**SE**	**95% CI**	
Time	6.38		1.93	[3.53, 11.53]	
Intercepts	12.95		7.13	[4.40, 38.12]	
Time#Intercepts	-6.65		3.41	[-13.33, .03]	
Residual	11.93		1.65	[9.09, 15.65]	

The quantitative findings for RQ1 demonstrate a clear surge in the use of technology-integrated activities among Taiwanese in-service Chinese teachers in literacy instruction during and after the COVID-19 pandemic. This observation strongly aligns with prior research indicating that the pandemic acted as a major catalyst for accelerating instructional technology integration globally (Alajmi, 2022; Eutsler et al., 2023; Winter et al., 2021). Our results thus reinforce the notion that significant chronosystem-level shifts, such as a global pandemic, can profoundly and rapidly alter educational practices.

Within Bronfenbrenner's (1979) Ecological Systems Theory, our findings underscore the dynamic interplay between the chronosystem (the pandemic as a historical event), the exosystem (professional development), and the macrosystem (socioeconomic context). The exosystemic influence of professional development was particularly evident, as teachers who engaged in more PD exhibited a greater increase in technology use during the pandemic. This highlights the crucial role of external, structured learning opportunities in equipping teachers to adapt to rapid changes. This finding resonates with the literature on professional development's capacity to enhance teachers' technological pedagogical content knowledge (TPACK) and facilitate effective technology integration (Mishra & Koehler, 2006; Qiu et al., 2022). It suggests that continuous professional learning is vital for teachers to effectively navigate the evolving landscape of technology-assisted instruction, helping to bridge the second-level Digital Divide by fostering skills and confidence (Borko, 2004; Wei et al., 2011).

However, the marginally significant interaction effect between time and SES for the suburban group after the pandemic introduces a nuanced perspective on the macrosystem's influence and the Digital Divide. While overall technology use increased, the less pronounced rise in suburban schools compared to urban and remote counterparts suggests that digital inequity extends beyond simple access (first-level Digital Divide). This finding aligns with the concept of teachers acting as "gatekeepers" of technology (Barzilai-Nahon, 2006), where their preferences, attitudes, and contextual interpretations, even amidst increased resources or training, can significantly shape technology integration. This observation is particularly interesting when compared to Natriello

(2001) and Graves and Bowers (2018), who found that teachers in lower-SES contexts often limit technology use to basic drills, while high-SES contexts favor versatile pedagogical integration. Our data, showing remote areas demonstrating a more pronounced increase in technology integration than suburban areas, adds a complex layer to this understanding. While Milton and Vozzo (2013) also indicated increased teacher technology integration over time in varied settings despite first-level digital divides, our results imply that the interplay of macrosystemic factors (like SES) with other ecological levels can produce unexpected patterns in technology adoption. This suggests that the second-level Digital Divide, pertaining to the quality and purpose of technology use, remains a critical concern, warranting further investigation into whether this increased use reflects a shift toward more substantive and pedagogically meaningful practices, or merely an increase in volume (Natriello, 2001).

These quantitative findings are further enriched and contextualized by the qualitative interview data. Teachers explicitly described a dramatic shift in their practices, adopting specific tech-assisted activities such as using 雄筆順 (Hsiung Stroke Order) for character writing and Browse 教育生活家 (Education Life) and 因材網 (Taiwan Adaptive Learning Platform) for Reading Certification and Reading Comprehension assessments. This triangulated evidence vividly illustrates the microsystem-level adaptations occurring in classrooms. The qualitative data also revealed two crucial sub-themes related to educational technology: disparities in accessibility and usability of tools. More experienced or self-motivated teachers actively sought out professional development and shared resources, showcasing individual agency within the exosystem. Critically, participants noted that even when schools provided adequate technological devices (addressing the first-level Digital Divide), many were poorly suited for literacy instruction or teachers lacked the knowledge and support for meaningful integration. This powerfully underscores that simply bridging the first-level Digital Divide is insufficient; if teachers lack the technological pedagogical content knowledge (TPACK) and confidence (influenced by the exosystem and potentially the macrosystem), the second-level Digital Divide will persist, limiting technology's genuine impact on student learning.

Research Question 2: How did the types of technology equipment in Chinese literacy instruction differ before and after the pandemic across schools with varying socioeconomic contexts, considering in-service teachers' levels of teaching experience and their participation in professional development programs?

The Mixed-Effects Model predicting the use of technology equipment (Table 5) showed a significant increase in the diversity of equipment used after the pandemic (b=1.57, SE=2.22, p<.001). Teachers with greater teaching experience utilized a more diverse range of equipment (b=.26, SE=.53, p=.022). The SES suburban group exhibited a smaller increase in technology use compared to the SES remote group (b=-.44, SE=1.28, p=.043). Teachers with greater participation in professional development exhibited a significantly greater increase in the use of diverse technology equipment over time (b=.17, SE=.27, p=.031). Significant variability was observed among teachers in the initial levels of technology use ($\sigma 2$=2.99, SE=1.37).

Table 5.

Mixed-Effects Model Predicting Equipment

Fixed effect	**Unstandardized *b***	**Standardized *b***	**SE**	**z**	**p**
Time_during pandemic	9.34	1.57	2.22	4.21	<.001
Age	-0.21	-.34	0.06	-3.27	<.01
Gender_female	0.00	.00	0.66	0.00	0.997
PD	-0.21	-.06	0.22	-0.94	0.348
TE	1.21	.26	0.53	2.29	<.05
SES_suburban	1.10	.19	1.04	1.06	0.291
SES_remote	-0.31	-.05	0.97	-0.32	0.752
Time_during pandemic#SES_suburban	-2.59	-.44	1.28	-2.02	<.05
Time_during pandemic#SES_remote	-0.72	-.12	1.15	-0.62	0.533
Time_during pandemic#PD	0.58	.17	0.27	2.16	<.05
Time_during pandemic#TE	-0.63	-.13	0.37	-1.70	0.089
_cons	10.19		2.28	4.47	<.001

Random-effects	**Variance**		**SE**	**95% CI**
Intercepts	2.99		1.37	[1.22, 7.36]
Residual	10.56		1.46	[8.05, 13.86]

The statistical analysis for RQ2 reveals a significant increase in the diversity of technology equipment used in Chinese literacy instruction after the pandemic. This echoes our findings for tech-integrated activities from RQ1, reinforcing the notion that the chronosystemic shock of the COVID-19 pandemic profoundly spurred technology adoption in education (Alajmi, 2022; Eutsler et al., 2023; Winter et al., 2021). Within the Ecological Systems framework, this increase points to the adaptability of the educational system, particularly as it responds to broad historical events.

Our findings further illuminate how various ecological levels mediate this adoption. The positive correlation between greater teaching experience and a wider range of equipment use highlights the influence of individual teacher characteristics within the microsystem (individual teacher's accumulated knowledge and practice) and potentially the mesosystem (how experience informs classroom and school-level practices). This aligns with prior research by Han et al. (2017), which emphasized the role of teaching experience in shaping technology use, and Huang (2015), which demonstrated how teachers' prior knowledge informs effective technology integration. Experienced teachers, having navigated various pedagogical challenges, may possess a greater capacity to discern and integrate diverse tools effectively.

The significant increase in equipment diversity among teachers with higher levels PD participation further underscores the crucial role of the exosystem in shaping technology integration. This finding converges with existing literature emphasizing that high-quality PD can bridge the second-level Digital Divide by enhancing teachers' knowledge and skills for meaningful

technology use (Borko, 2004; Christ et al., 2019; Wei et al., 2011). It suggests that targeted training helps teachers not only adopt technology but also diversify their toolkit, fostering greater confidence and competence (Klassen & Tze, 2014) in navigating the rapidly evolving technological environment. This echoes the TPACK framework (Mishra & Koehler, 2006), where PD is critical for developing integrated technological, pedagogical, and content knowledge, leading to more varied and effective equipment application.

However, the observation that the SES suburban group exhibited a smaller increase in technology equipment use compared to the remote group introduces a complex dynamic within the macrosystem. This outcome is particularly interesting as it diverges from some general assumptions about the Digital Divide where remote or lower-SES areas might be expected to lag in technology adoption (Ritzhaupt et al., 2013). Instead, our finding suggests that the factors influencing the second-level Digital Divide (i.e., patterns and quality of use) are not solely dependent on conventional SES indicators or resource access. Teachers' individual attitudes, preferences, and agency, influenced by their local context, appear to play a significant role as "gatekeepers" of technology (Barzilai-Nahon, 2006). The relatively greater increase in remote areas, for instance, might be attributed to a stronger necessity or a more pronounced policy push for digital solutions in settings where traditional resources might be scarce, aligning with findings from Head et al. (2023) about well-designed PD in low-resource settings. This indicates that overcoming the first-level Digital Divide (access) doesn't automatically eliminate disparities in how technology is adopted and diversified in practice.

Our qualitative results provide critical nuance to these quantitative findings, especially concerning the second-level Digital Divide. Interviews reinforced observations by Christ et al. (2019) that teachers, particularly those less experienced, struggled to align technology choices with instructional goals and manage student engagement effectively. Interviewees consistently emphasized the exosystemic necessity of PD for understanding meaningful technology integration. Moreover, participants voiced concerns about the unsuitability of certain tech tools for lower-grade students and viewed technology as a "double-edged sword" – useful yet distracting. The emergence of subthemes under "Writing Challenges," such as the foundational importance of paper-based handwriting and vocabulary challenges potentially exacerbated by digital media, highlights that technology's role in literacy development may not be universally positive. These qualitative insights demonstrate how microsystem-level challenges (e.g., specific student needs, practical application issues) can influence the quality and effectiveness of technology integration, even when access to diverse equipment is increasing (chronosystem). This reinforces the conceptual tenet that merely providing tools (addressing the first-level Digital Divide) does not guarantee pedagogically sound and effective use, highlighting the persistent challenges of the second-level Digital Divide in actual classroom practice.

Research Question 3: What challenges did in-service teachers encounter in integrating technology into Chinese literacy instruction, and how did these challenges vary by school context, experience level, and professional development access?

Our qualitative data analysis, derived from interviews with in-service Chinese language teachers, revealed three primary, shared challenges that transcended school SES and teacher experience. These challenges illuminate the complex interplay of various ecological levels in shaping technology integration.

The first significant challenge was device incompatibility or inappropriateness, particularly for younger learners. Teachers frequently reported that the digital tools provided or commonly

available were not optimally designed for early literacy instruction. As Ms. Lin (remote, experienced) articulated:

> *"平板電腦對低年級來說不好用，鍵盤太小，打字很慢。"*
>
> *"Tablets are not good for lower grades; the keyboards are too small and slow for them to type."*

This challenge highlights a critical mismatch within the microsystem (the classroom environment and student developmental needs) concerning the exosystemic provision of technology.

Secondly, teachers commonly pointed out that digital platforms, such as tablets and computers, frequently served as a source of student distraction, pulling attention away from core literacy tasks. Ms. Huang (urban, experienced) noted this widely observed issue:

> *"平板裡面有太多誘惑，學生容易分心。"*
>
> *"There are too many temptations on the tablet, and students are easily distracted."*

This points to a microsystem-level challenge related to managing the inherent nature of digital tools within the learning environment.

Finally, a prevalent challenge across all contexts was the limited scope and content PD. Even when teachers participated in PD workshops, most sessions focused on general digital tool operation rather than content-specific applications for Chinese literacy instruction. As Mr. Wang (suburban, early career) expressed:

> *"多數培訓都偏向應用程式操作，不是針對國語文教學。"*
>
> *"Most of the training is oriented towards the operation of application programs, rather than the teaching of the Chinese language."*

This limitation within the exosystem directly impacts teachers' ability to translate broad technological knowledge into effective pedagogical practices within the microsystem.

Challenges by school context (macrosystem and exosystem). Our qualitative findings further revealed how these challenges varied across different school socioeconomic contexts, illustrating the nuanced influence of the macrosystem on technology integration. In urban schools, where teachers often benefited from more extensive resources (suggesting stronger macrosystemic support for technology access), teachers like Ms. Huang (urban, experienced) still reported significant challenges with classroom management during technology integration. Despite her long-term experience with technology:

> *"即使我已經用了很多年科技，但學生還是會分心，而且 PD 沒有教我們怎麼有效地管理課堂。"*
>
> *"Even though I've used technology for many years, students still get distracted, and PD doesn't teach us how to manage classrooms effectively."*

This highlights a mesosystemic disconnect between accessible resources and effective pedagogical strategies.

Conversely, in suburban schools, where there was adequate access to technology, the alignment between tool selection and students' developmental stage remained a limitation. Mr. Wang (suburban, early career) articulated this:

“我們有設備，但很多軟體不適合國小學生，有些資源是為中學生設計的。”

“We have devices, but many programs are not suitable for elementary students; some are designed for secondary school learners.”

“PD 講的是怎麼操作電腦，但沒有講怎麼結合教學目標。”

“PD focuses on how to operate the computer, but not how to align it with teaching objectives.”

These insights from suburban teachers underscore how the exosystemic provision of tools and PD, even when present, may not sufficiently address microsystem-level pedagogical needs.

For teachers in remote areas, challenges primarily revolved around infrastructural and resource deficits. Ms. Lin (remote, experienced) described:

“我們的平板是政府配的，但很舊，有的還不能開機。”

“The tablets provided by the government are outdated; some of them don’t even turn on.”

“我們的學生有些家裡是第一次接觸平板，他們不知道怎麼操作。”

“Some of our students are using tablets for the first time at school; they don’t even know how to use them.”

“雖然疫情後我們有更多的設備了，但教學活動還是以填鴨和抄寫為主。”

“Although we got more devices after the pandemic, the main instructional activities are still drill-based and copying.”

This illustrates the persistence of the first-level Digital Divide at the macrosystemic (governmental provision) and exosystemic (school-level equipment) levels, directly impacting the quality of microsystemic instruction. The continued reliance on drill-based activities, despite increased device access, points to a clear second-level Digital Divide, where superficial use predominates over cognitively meaningful integration (Natriello, 2001; Graves & Bowers, 2018).

Challenges by teacher experience level (exosystem and microsystem). The interview data also revealed variations in concerns based on teachers’ experience levels, highlighting the influence of the exosystem (professional background) and microsystem (individual capabilities).

Early career teachers, such as Mr. Wang (suburban, early career), expressed significant anxiety about integrating technology, often resorting to trial and error and peer support due to a lack of formal guidance:

“剛開始完全不知道從哪裡開始，只能問別的老師。”

“I had no idea where to start, so I had to ask other teachers.”

This contrasts with the literature suggesting experienced teachers deliver more effective technology-integrated literacy instruction (Fahrman et al., 2020). Indeed, our findings show that experienced teachers tended to focus more on integrating technology effectively rather than just what tools to use. They actively engaged in various exosystemic professional development avenues, including social media platforms, workshops, and certification programs, as exemplified by Ms. Chen (urban, experienced):

“我會追蹤出版社的粉專，只要有研習我就會報名參加。”

“I follow all major publishers’ Facebook pages and register for any training workshops they offer.”

"我自己是Google、Apple認證的教師。"

"I'm certified as a Google and Apple educator."

However, despite their expertise, experienced teachers also voiced frustration when PD lacked instructional depth and failed to support meaningful classroom application. This reflects a mesosystemic gap between PD content and practical classroom needs. Ms. Huang (urban, experienced) articulated this tension:

"老師還是要上課還是要管理學生，我們只會被要求操作而已。"

"We're still responsible for teaching and classroom management, but PD only trains us on how to operate the devices."

Moreover, some experienced teachers acknowledged their own resistance to adopting new practices due to established routines, suggesting that accumulated experience can sometimes be a barrier to innovation within the microsystem:

"像我們資深一點的，對這種操作比較有抗拒。"

"Senior teachers like us tend to be more resistant to this kind of technology use."

This finding aligns with Han, Shin, and Ko (2017), who indicated that differences in teaching experiences and beliefs can contribute to unequal classroom technology use. It also suggests a potential trade-off where experienced teachers' strong content and pedagogical knowledge (CK and PK) might not be fully leveraged without integrated technological pedagogical content knowledge (TPK) and technological content knowledge (TCK) provided by relevant PD (Mishra & Koehler, 2006).

Professional development access and impact (exosystem). Finally, the interview data specifically suggested that teachers who actively participated in multiple professional development workshops demonstrated greater creativity and flexibility in integrating technological tools. For instance, Ms. Lin and Ms. Chen, both active PD participants, showcased diverse approaches. Conversely, Mr. Wang, an early-career teacher, relied more on informal mesosystemic supports like peer support and online tutorials. Ms. Huang, despite her experience, found that her teaching philosophy did not align well with the focus of available technology PD, limiting its practical application in her classroom. This underscores how the nature and alignment of exosystemic PD significantly mediate its impact on teachers' microsystemic practices.

Our qualitative findings offer critical insights into the multifaceted challenges teachers face in integrating technology into Chinese literacy instruction, providing a nuanced understanding of how these challenges are shaped by various ecological levels. The pervasive issues of device inappropriateness for young learners and student distraction highlight significant microsystemic and mesosystemic challenges. These findings align with broader post-pandemic realities described by Christopoulos and Sprangers (2021), where educators grapple with the practicalities of technology use, including issues of engagement and pedagogical effectiveness. This reiterates that merely providing access to technology (addressing the first-level Digital Divide) is insufficient if the tools themselves are not developmentally appropriate or if teachers lack strategies for managing their use effectively within the classroom.

Crucially, the consistent feedback on PD lacking content-specific and pedagogical depth points to a major shortfall within the exosystem. This directly corroborates the tenets of Mishra and

Koehler's (2006) TPACK framework. Teachers emphasized that PD focused solely on operational skills (Technological Knowledge, TK) without integrating it with Content Knowledge (CK) and Pedagogical Knowledge (PK) to form comprehensive TPACK, particularly Technological Pedagogical Knowledge (TPK) and Technological Content Knowledge (TCK). This gap limits teachers' capacity for meaningful classroom application, contributing significantly to the second-level Digital Divide as teachers struggle to translate technological capability into enhanced literacy instruction. This echoes Voogt and McKenney's (2017) findings regarding fragmented curricula and limited support for integrated TPACK in teacher education.

The variations in challenges across school SES contexts (macrosystem) further deepen our understanding of the Digital Divide. While urban schools had better resources, they still faced classroom management issues, suggesting that technological sophistication doesn't automatically translate to seamless integration. Suburban schools, despite good access, struggled with tool-student developmental alignment, indicating a mesosystemic misalignment between available technology and specific instructional needs. Most critically, remote schools continued to battle outdated equipment and limited broadband, directly reflecting persistent first-level Digital Divide challenges (Reinhart et al., 2011). Ms. Lin's report from a remote area, noting continued reliance on "drill-based and copying" despite increased device access, strongly supports the existence of a second-level Digital Divide rooted in a lack of support for cognitively enriching applications (Graves & Bowers, 2018; Natriello, 2001). This absence of collaborative, pedagogically grounded applications in remote areas further highlights a systemic gap in fostering meaningful technology use.

Furthermore, the influence of teacher experience (exosystem) emerged as a critical mediating factor. Early-career teachers experienced significant anxiety and a reliance on informal support, suggesting that more structured guidance is needed to build their confidence and competence (Han et al., 2017). Conversely, while experienced teachers actively sought out PD and advanced certifications (reflecting their proactive engagement within the exosystem), they also expressed frustration with generic PD and, in some cases, a resistance to fundamentally alter established routines. This confirms Han, Shin, and Ko's (2017) assertion that differences in teaching experiences and beliefs contribute to varied technology use. It also suggests that for experienced educators, simply increasing access to PD is insufficient; the quality and content of PD must address integrated TPACK to encourage deeper shifts in pedagogical philosophy and practice.

Conclusion, Limitations and Directions for Future Research

This study aimed to investigate the professional growth trajectory of in-service Chinese teachers in Taiwanese elementary schools regarding technology-assisted literacy instruction during the pandemic era, and how factors of the Digital Divide influenced their growth across various ecological contexts. Our mixed-methods findings extend Bronfenbrenner's (1979) ecological theory by uncovering novel and intricate interactions across ecological levels, particularly within the context of technology integration.

Summary of Major Findings

Our research revealed several key conclusions spanning the chronosystem, macrosystem, exosystem, and microsystem:

First, concerning Research Question 1 (RQ1), there was a significant and sustained increase in the diversity of *technology-integrated activities* in Chinese literacy classrooms during and after the COVID-19 pandemic. This highlights the powerful impact of a chronosystemic event (the

pandemic) in accelerating educational technological adoption. This growth was notably more pronounced among teachers who actively engaged in exosystemic professional development, reinforcing the critical role of structured support in adapting to rapid changes. However, the marginally significant interaction effect between time and SES for suburban schools suggested a more complex influence of the macrosystem, where the increase in technology-integrated activities was less pronounced compared to urban and remote counterparts, hinting at nuanced second-level Digital Divide disparities beyond mere access.

Second, for Research Question 2 (RQ2), we observed a significant increase in the *diversity of technology equipment* used after the pandemic. Teachers with greater teaching experience and higher participation in professional development utilized a wider range of tools, emphasizing the mediating roles of the exosystem (professional experience and PD) in technology adoption. Similar to RQ1, the smaller increase in equipment diversity among suburban schools compared to remote schools underscored that the second-level Digital Divide persists, influenced by factors beyond access. These findings collectively suggest that while the pandemic (chronosystem) drove increased technology and equipment use, individual teacher attributes and contextual factors (microsystem, exosystem, macrosystem) critically shaped the extent and nature of this integration.

Finally, regarding Research Question 3 (RQ3), our qualitative analysis illuminated *persistent challenges* that tempered the observed increases in technology use. These included widespread issues of device incompatibility or inappropriateness for young learners and student distraction within the microsystem. A critical challenge at the exosystemic level was the prevalent focus of professional development on general tool operation rather than content-specific and pedagogical strategies for Chinese literacy. While macrosystemic factors like school SES influenced the types of challenges (e.g., resource disparities in remote areas vs. classroom management issues in urban schools), the fundamental disconnect between technology provision and meaningful pedagogical application remained. Teacher experience also played a mediating role, with early-career teachers exhibiting anxiety and experienced teachers sometimes expressing resistance to changes that lacked pedagogical depth. These challenges underscore that the top-down digital implementation mandates from the government policy due to the pandemic (chronosystem) facilitated teachers' increasing technology-supported activities, especially in urban and remote areas, but these changes did not always translate into cognitively meaningful literacy instruction (microsystem). Overall, the findings align with the post-pandemic realities described by Christopoulos and Sprangers (2021), highlighting persistent access disparities, digital fatigue, and a misalignment with curriculum goals. The data consistently highlighted the role of teachers' experience and professional development communities (exosystem) as crucial mediating spaces where macrosystemic (SES) and chronosystemic (pandemic) policy goals were interpreted and negotiated.

Limitations and Directions for Future Research

Despite these unique contributions, the present study has several limitations that offer valuable directions for future research. First, due to funding and logistical constraints, only 111 participants were recruited for the quantitative survey. A larger sample would enable more sophisticated statistical analyses, such as structural equation modeling (SEM) to test the hypothesized relationships between ecological levels more rigorously, or latent growth modeling to further explore individual growth trajectories in technology use over time, beyond the current time-point comparisons.

Second, the qualitative component of our study, while providing rich insights, was limited by the participation of only four teachers in the focus group interviews due to budget constraints and lack of incentives. Future research employing a larger and more diverse group of interviewees would allow for greater thematic saturation, capturing a broader range of teacher experiences, perceptions, and nuanced ecological interactions.

Third, although our analytic model includes a time variable, the study design is cross-sectional, with data collected at a single time point based on retrospective self-report. As such, the design limits our ability to draw causal inferences about change over time. Longitudinal tracking of individual teachers' practices would provide more robust evidence regarding growth trajectories and the temporal effects of ecological factors.

Last but not least, this study was conducted exclusively in Taiwan. Future research conducted in other Chinese-speaking regions, such as Hong Kong and Mainland China, would offer a more comprehensive understanding of technology-integrated Chinese literacy instruction. These regions present unique linguistic and pedagogical contexts, including distinct script features (e.g., traditional vs. simplified characters), different literacy instruction approaches (e.g., the use of Pinyin in Mainland China versus a more "look-and-say" approach in Hong Kong), and varying educational policies and technological infrastructures. Such comparative studies could shed light on how specific macrosystemic and chronosystemic factors shape technology integration within diverse Chinese literacy ecologies.

Implications

Despite these limitations, the conceptual framework developed for this study, grounded in Bronfenbrenner's Ecological Systems Theory and the Digital Divide, along with the empirical findings, offers unique and vital contributions to the field, carrying significant implications for scholarship, policymaking, and practitioners.

Implications for scholarship. This study significantly advances scholarship by providing empirical evidence for the dynamic interplay between the chronosystem (the pandemic), macrosystem (SES), and exosystem (teaching experience, PD) in shaping microsystemic technology integration practices in a non-Western literacy context. It moves beyond a linear understanding of technology adoption, illustrating how multiple interconnected ecological levels mediate teachers' professional growth. The findings highlight the continued relevance of the second-level Digital Divide, emphasizing that access alone does not guarantee meaningful integration, and calls for further theoretical development to understand teacher agency within complex, multi-level systems. Future research should leverage these insights to build more sophisticated models that capture these dynamic interactions and explore their long-term effects on student literacy outcomes.

Implications for policymaking. Our findings offer concrete implications for educational policymakers. Governments and educational authorities should move beyond simply providing digital equipment (addressing the first-level Digital Divide) and focus on policies that support the quality and pedagogical alignment of technology use (addressing the second-level Digital Divide). This includes:

Investing in context-specific PD. Mandating and funding professional development programs that are specifically designed for Chinese literacy instruction and integrate Technological Pedagogical Content Knowledge (TPACK), rather than generic software operation.

1. ***Curating appropriate tools.*** Policies should encourage the development and procurement of digital tools that are developmentally appropriate for young learners and align with the unique demands of Chinese character learning and literacy instruction,
2. ***Addressing nuanced inequities.*** Policymakers must acknowledge that digital inequities are not solely defined by urban-rural divides but can manifest in unexpected ways, such as the less pronounced growth in suburban areas. Targeted interventions may be needed to understand and address region-specific barriers to meaningful technology integration, and
3. ***Supporting sustained integration.*** Policies should foster ongoing support structures for teachers, recognizing that technology integration is a continuous process that evolves with new challenges like digital fatigue.

Implications for practitioners. For teachers, school administrators, and professional development providers, our study provides actionable insights:

1. ***For Teachers.*** Recognize that effective technology integration extends beyond mere tool operation. Actively seek professional development that integrates technology with literacy pedagogy. Be mindful of potential student distraction and proactively implement strategies for effective classroom management during digital activities. Experienced teachers can leverage their rich pedagogical knowledge to critically evaluate new technologies and mentor early-career colleagues,
2. ***For School Administrators.*** Move beyond simply acquiring technology to strategically investing in tools that are developmentally and pedagogically appropriate for literacy instruction. Prioritize and fund high-quality, continuous professional development that focuses on integrated TPACK and addresses specific challenges within your school's context. Foster a supportive mesosystem within the school that encourages collaboration and sharing of best practices regarding technology integration among teachers, and
3. ***For Professional Development Providers.*** Design programs that are highly relevant to Chinese literacy instruction, explicitly bridging the gap between technological knowledge and pedagogical practice through the TPACK framework. Incorporate strategies for classroom management in digital environments and consider the varied experience levels of teachers. Tailor content to address the unique needs identified in different school contexts (e.g., addressing outdated equipment challenges in remote areas, or deeper pedagogical integration in suburban schools).

In conclusion, the post-pandemic educational landscape demands a holistic approach to technology integration that recognizes the complex interplay of ecological factors. Our study, despite its limitations, provides foundational insights into this dynamic in the Chinese literacy context, offering crucial guidance for empowering teachers to truly bridge the digital divide and foster meaningful technology-enhanced literacy learning for all students.

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