

Brief Report

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ChatGPT Supporting Heritage Language Literacy in Underserved Communities: A Neurocognitive Study of Sociolinguistic Factors

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Abstract: Heritage Language (HL) has been used as an umbrella definition to cover different facets of non-official/dominant languages (i.e., non-English in North America) within communities. Overall heritage language proficiency is highly related to literacy and general cognitive development. In America's Deep South states like Alabama, the three largest heritage languages are Spanish, Chinese, and Gujarati. Despite some parental investment and little governmental support in HL programs and schooling, most K-16 heritage language learners have a disparity between oracy, literacy, and overall HL proficiency. To remedy this discrepancy, we explore how generative AI provides Chinese Heritage Language (CHL) learners with tailored real-time feedback and observe how their literacy level changes with different social entities. By examining the influences of social-cultural factors on HL learners, we aspire to augment our comprehension regarding the efficacy of pedagogical modalities in equipping them to acquire advanced literacy. Surveys will be administered to evaluate participants' familial, educational, and communal backgrounds, level of proficiency in HL, and attitudes toward AI models. ChatGPT3.5-4o will generate reading materials, with Prompt Engineering Techniques (PET) and Prompt-engineered Leading Protocols (PLP) designed for CHL learners at the beginning, intermediate, and advanced levels. To investigate the motivations to use AI and its impact on language learning, this study invites participants to engage in a six-month HL study by following pre-trained prompts and interacting with ChatGPT with the intensity, frequency, and duration specified by the learning protocol. Students' and parents' reports, periodic progress assessments, AI usage reports, and

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electrophysiological measurement (EEG) will be collected at the study's initial, middle, and end times. This project will hold significant implications for AI tools' role in bridging resource gaps in literacy and cognitive development in underserved communities.

Keywords: heritage language; ChatGPT; prompt engineering; Chinese; EEG

Broadly speaking, Heritage Language (HL) covers different facets of non-official or dominant languages (i.e., non-English in North America) within communities. HL proficiency is highly related to literacy and the general cognitive development of learners. However, in America's Deep South states, such as Alabama, there is little communal investment or governmental support for HL programs and schooling. Many Heritage Language Learners (HLLs) have a disparity among oracy, literacy, and overall HL proficiency. To remedy this discrepancy, we explore how AI provides Chinese Heritage Language (CHL) learners with tailored real-time feedback and observe how their literacy changes with different social entities. By examining the influences of social-cultural factors on HL learners, we aspire to enrich our understanding of the progress in literacy and cognition. Setting a blueprint for a large longitudinal research project, we organize this report based on Burnard's framework (2004) for a *Research Report in Progress*, including background, research questions, literature review, methodology, preliminary findings, and conclusion.

1 Background

The importance of heritage language extends beyond mere communication; it embodies the cultural and ethnic identities of individuals and communities. Fishman (2014) underscores HL's connection to ethnicity, ancestry, and cultural heritage. Rothman (2009, 156) suggests that "a language qualifies as an HL if it is spoken at home or otherwise readily available to young children and is not the dominant language of the larger society." Aalberse et al. (2019) further elaborate that HL deals with learners' language shift, where the dominant language gradually replaces heritage languages. This phenomenon highlights the vulnerability of HLs and the need for effective pedagogical strategies and policymaking to preserve and promote them.

At both individual and societal levels, Heritage Language Education (HLE) preserves languages, cultures, histories, and identities within individuals and ethnic communities (Duff and Doherty 2019; He 2006, 2013; He and Xiao 2008). HLE also addresses the growing national demand for foreign language proficiency across various sectors, including trade, technology, politics, diplomacy, military affairs, and

national security (McGinnis 2008; McGinnis and Wang 2020). Furthermore, HLE transcends cultural boundaries, fosters mutual respect, and cultivates empathy, enabling recognition of the humanity and legitimacy of all peoples (Nussbaum 1997, 2011, 2017; Zhang and Petrovic 2026).

From linguistic and psycholinguistic perspectives, natural bilingualism in spoken and written forms significantly improves proficiency and literacy development in both languages. Studies on diverse populations, either Greek-English bilinguals in Greece, HL learners of Spanish in Afro-Bolivia, Chinese speakers in the United States, or Setswana HL speakers in South Africa, demonstrate that phonological awareness acquired through HL learning can transfer to dominant languages, particularly for students with strong HL literacy skills (Durgunoglu et al. 1993; Kim et al. 2025; Niolaki and Masterson 2012; Rao and Sessarego 2016). The theories and findings that literacy skills can transfer between first and second languages (Koda and Zehler 2008; Wang and Yang 2008) illustrate the importance of maintaining heritage languages and understanding the unique profiles of the learners (Brinton et al. 2017; Carriera and Kagan 2018; Cummins 1983; Peyton et al. 2001). However, the irregular distribution of HLs, HLLs, and resources across the United States has posed challenges for conducting analyses of heritage languages at the national level.

1.1 The Disparity of HLs in the United States

According to the U.S. census, the highest HLL populations are located around metropolitan cities with intensive immigration: Seattle, Los Angeles, Houston, Miami, Phoenix, Denver, Chicago, and the New York-DC-Boston area (Figure 1). All these areas host more than 1,000,000 individuals who use a language other than English at home. In contrast, most of the country, including the primary regions of the Deep South such as Alabama, Mississippi, Georgia, Louisiana, South Carolina, North Florida, East Texas, East North Carolina, and South Tennessee, lacks any one area with a concentration of HLLs above 1,000,000 individuals (Map 2022).

This geographic distribution poses difficulties in fostering communities among the scattered existence of HLLs, thereby limiting the resources available to support HL programs. Selecting the demographic data (Figure 2) from Alabama, Mississippi, and Georgia, we have a clearer understanding of the situations of HLLs in the Deep South. As illustrated in the following chart, each state has over 50,000 such households: Georgia with 681,233 (Note: this number should be much less if without Atlanta), Alabama with 135,971, and Mississippi with 59,932.

Of these, Spanish is the largest group in all states in the above chart, with more than 30,000 households per state, while all other languages have fewer than 10,000 households (Language Use in the United States 2019). Because of the distribution

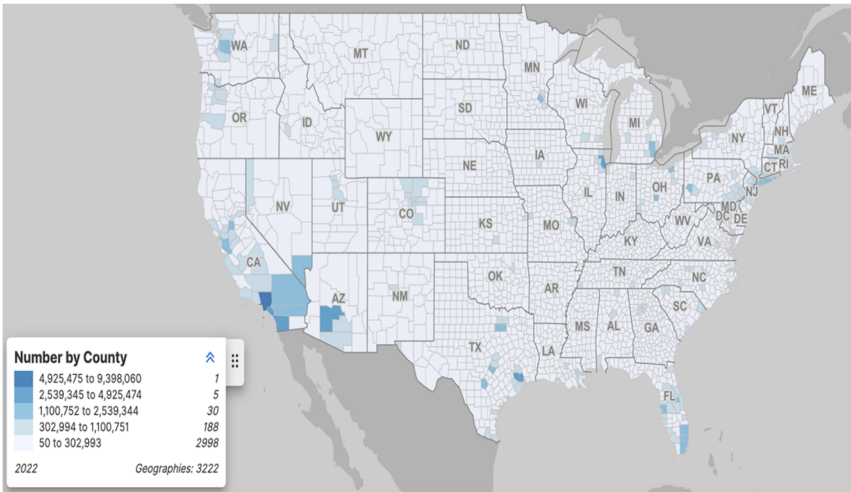


Figure 1: Population above five years old speaking a language other than English at home by County.

discrepancy in the total HLL population and the languages they speak, HLLs of languages other than Spanish face difficulties in finding strong communal support. While resources for maintaining HLs are readily available in major metropolitan areas, learners in non-metropolitan regions struggle in accessing the already limited (in)formal classroom instruction and learning materials. This disparity raises critical questions about their right to equitable language education opportunities.

Label	Alabama		Georgia		Mississippi	
	Estimate	Margin of Error	Estimate	Margin of Error	Estimate	Margin of Error
▼ Total:	2,051,545	±10,192	4,150,138	±14,424	1,166,617	±7,610
English only	1,915,574	±10,710	3,468,905	±17,974	1,106,685	±7,922
> Spanish:	77,257	±3,066	345,390	±7,061	34,058	±2,310
> French, Haitian, or Cajun:	4,653	±1,161	33,062	±3,708	2,508	±874
> German or other West Germanic languages:	8,523	±1,527	17,584	±2,344	2,521	±891
> Russian, Polish, or other Slavic languages:	1,997	±779	15,800	±2,325	839	±542
> Other Indo-European languages:	12,076	±1,756	76,378	±4,842	3,998	±1,037
> Korean:	6,170	±1,054	25,304	±2,480	871	±422
> Chinese (incl. Mandarin, Cantonese):	4,822	±1,070	28,265	±2,700	3,175	±1,047
> Vietnamese:	4,015	±1,046	20,000	±2,057	2,939	±1,166
> Tagalog (incl. Filipino):	2,866	±703	9,656	±1,546	1,706	±686
> Other Asian and Pacific Island languages:	5,825	±1,118	43,293	±3,234	2,558	±1,065
> Arabic:	2,670	±873	9,837	±1,962	1,573	±760
> Other and unspecified languages:	5,097	±1,625	56,664	±4,874	3,186	±1,009

Figure 2: Number of households speaking a language other than English in Alabama, Georgia, and Mississippi.

1.2 Limited HLE Resources

Outside the context of in-family language education, K-16 HLE in the United States primarily follows two institutional trajectories: (1) mainstream language education (Luo et al. 2019; Li and Duff 2008) and (2) community-based heritage language schools (CHLS). In higher education, HLLs have benefitted from more structured institutional support, though this support remains uneven across different heritage languages. A 2014 national report found that approximately 48 percent of university foreign language programs offered courses specifically designed for HLLs. However, the availability of such classes varied by language, with 80 percent of Spanish departments offering dedicated HL courses compared to only 55 percent of Chinese programs (Carreira 2014). Even though by 2017, the proportion of institutions offering HL support had increased to 73 percent, much of this progress has been driven by the individual efforts of professors rather than by comprehensive institutional policies (Carreira 2017). In K-12 education, mainstream language education includes a range of bilingual models. Recent studies report the existence of 312 Chinese Dual Language and Immersion (DLI) programs in U.S. public schools (Roberts 2021; Sung and Tsai 2019). However, this number pales in comparison to the 2,936 Spanish DLI programs nationwide. Therefore, many heritage languages in the U.S., such as Chinese, Japanese, and Russian, rely heavily on ethnic communities for support through CHLS (Carreira and Kagan 2018; Liu 2010; Silver 2003).

As shown in the map (Figure 3), there are over 300 schools offering instruction in 36 heritage languages by communities. These schools are primarily located along the West Coast, East Coast, Central North, and Texas, as reported by the Coalition of Community-Based HL Schools (Lu 2019). The disproportionate distribution of pins on the map highlights that the Deep South regions face significant limitations in HL communal support. These challenges stem from the sparse distribution of cultural and ethnic groups and a lack of educational resources. To illustrate the issues and possible solutions, in this project, we employ AI tools to facilitate the CHL learning as a sample for possible solutions on HLE in underserved communities.

2 Research Questions

As advancements in technology continue, educators and researchers are searching for ways to integrate AI tools into language education. These technologies enable computer systems to understand and process human languages, perform tasks such as human-like conversations, collect information on specific subjects, and respond to human sentiment (Pruneski et al. 2022). Compared to traditional classroom teaching,

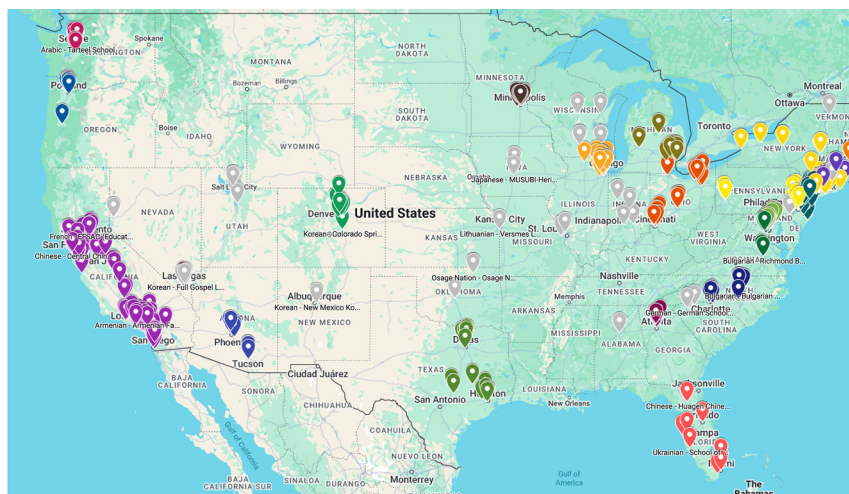


Figure 3: National coalition of community-based language schools map, 2024.

AI tools offer several advantages. For instance, AI can provide a large database of human knowledge, customize learning experiences tailored to individual student needs, continuously adjust learning content based on learners' progress without being constrained by physical infrastructure, and offer a more flexible learning environment (Olfert 2022; Wang et al. 2018). Therefore, we expect to harness AI tools to bridge the gaps in HL resources for learners in the Deep South, ensuring equitable educational opportunities for all language learners. In addition, we are curious to explore the long-term cognitive impact of these techniques on language development among these learners (Han 2024). The following central question guides our research: Can ChatGPT help enhance CHL learning outcomes in underserved communities by offering accessible and engaging learning tools? Specifically:

1. Are there discernible correlations among HLL-specific factors, such as sociolinguistic backgrounds, literacy levels, family and community support, and attitudes towards AI technology in HL learning, among parents, students and communities?
2. Can Chatbot AI tools such as ChatGPT3.5-4.0 assist in developing accessible heritage language text materials based on a pre-designed curriculum?
3. How do Prompt Engineering patterns facilitate the acquisition of logographic reading skills with large language models (LLMs)?
4. Will AI-based learning experiences enhance the HLLs' semantic and syntactic sensitivity in terms of salient changes in neural activities?

3 Literature Review

In the following literature review, we provide orientation to the key topics: the characteristics of heritage language learners, the state of Chinese in the American South, HSK standards and *Maliping* CHL textbooks, AI-assisting language learning through prompt-engineering patterns, and the neurocognitive factors influencing HLE. While all components are crucial for building a theoretical framework for this longitudinal research, we believe that the distinctive characteristics of HLLs are the cornerstone.

3.1 Heritage Language Learners (HLLs)

Although HLE is crucial to individual, communal, national, global, cognitive, and pedagogical development in multicultural societies, the heterogeneous nature of HL populations presents challenges to both the practice and research in this field (Montrul and Polinsky 2019). To better understand this group's unique characteristics, we visualize HLLs as evolving and growing agents within a temporal-spatial framework (e.g., the X-axis representing time and the Y-axis representing space/location in a quadrant). Heritage language learning, therefore, can be conceptualized as a dynamic life event for HLLs, reflecting, what psychologist James Gibson stated, the fluidity and continual change inherent in human experience (2014).

HLLs are often described as “bilingual child learners” or “childhood over-hearers” (Oh et al. 2019; Polinsky 2015, 164) because they benefit significantly from growing-up memory in retaining remnants of a HL. Temporally, HLLs' proficiency and familiarity with HLs vary due to numerous subjective and objective factors, including age, physical/cognitive development, duration of HL exposure, family immigration timelines, etc. Montrul (2010, 3) acknowledges HLLs' developmental trajectory, identifying the learners as “individuals who were exposed to an ethno-linguistic minority language within their family during childhood and, as adults, seek to learn, relearn, or enhance their linguistic proficiency in their heritage language.” In other words, every HLL encounters the dynamic HL experience to varying degrees at different phases of their life. The unique events of HLLs, such as body changes, incomplete language acquisition, fossilization, evolving motivations, re-immigration intervention, historical stages and socioeconomic status of home and host countries, etc., underscore the fluid nature of their identity and language proficiency over time.

Spatially, HLLs' proficiency levels are influenced by factors such as birthplace, physical transition between home and host countries, engagement with in-between spaces, access to media, technology and ethnic communities, availability of learning

resources, opportunities for formal HL education, and geographic distribution of immigrant diasporas. Those spatial factors inhabited by HLLs differ from those of Native Language Learners (NLLs) and foreign language learners (FLLs). Usually, HLLs display distinct characteristics in language input environments, learning mechanisms, attrition rates, and cultural knowledge (Cai 2022). While both NLLs and HLLs share naturalistic language environments, HLLs are more susceptible to heritage language attrition. In addition, HLLs' familiarity with the target culture often enhances listening comprehension and reduces anxiety, making listening tasks easier for them than FLLs (Xiao and Wong 2014). Hence, understanding the temporal and spatial distribution of HLL populations is critical for addressing disparities in access to HLE resources in the U.S., especially the South.

3.2 Chinese Diaspora in the Deep South

Chinese has the largest speaking population globally, with an estimated one billion speakers in 2022, including 950 million first-language speakers and 150 million foreign, second, or heritage language speakers (Bhatia and Ritchie 2013). In the United States, there were approximately 3.5 million HL speakers among the 5.7 million Chinese Americans in 2019, with 70 percent reporting the use of Mandarin Chinese (including unspecified varieties) at home, while 30 percent spoke other Chinese varieties (Dietrich and Hernandez 2022). Chinese immigrants had been reported in 2023 to have higher median household incomes than the overall foreign-born population (Migration Policy Institute 2023), with \$78,000. For Alabama, the state's population was 5.2 million in 2024, with approximately 1.6 % identifying as Asian (about 83,000 individuals) (Census of U.S. 2024). Chinese immigrants represent a portion, though specific numbers are not detailed. Considering that Chinese immigrants nationally constitute a majority of the Asian population (Census of U.S. 2024), we reasonably assume that the Southern Chinese diaspora has grown due to key national immigration waves of Taiwanese immigrants in the 1960s and Mainland Chinese immigrants in the 1980s.

The socioeconomic profile of Chinese immigrants has shifted over time. Earlier immigrants usually came from the low-income working-class in the 1800s, whereas the post-1960s waves have been marked by the arrival of highly educated professionals and elites. The new group, often identifying themselves as 华人精英 (*Huárén Jīngyīng*, or Elite Chinese), reside in suburban neighborhoods, uphold the traditions of the Chinese gentry, emphasize the preservation of the Chinese language (e.g., Mandarin and the Hanzi writing system) as a marker of their elite identity, and sometimes, display ethnocentrism (Zhang and Petrovic 2026). Therefore, the linguistic repertoires of these households exhibit the “hyperliteracy” of the middle-high class of

home countries, mirroring patterns identified by Valdés on the West Coast decades ago (2001, 44–45).

In the broader societal context, the American South continues to be influenced by racial and ethnic re-segregation (Boger and Orfield 2005; Owens 2020; Shearman et al. 2023). Traditional contentiousness between the White and Black Americans has overshadowed the struggles of smaller ethnic groups, such as, Hispanic, Chinese, Indian, Arab, etc. Although Chinese in the South were impacted less by the Chinese Exclusion Act in the 1800s, the social isolation comes from both White and Black communities.

Access to HLE is severely limited. For instance, Birmingham, the state's largest CHL hub, has only two community-based Chinese heritage language schools (CCHLS), serving 100–200 students. Smaller cities like Tuscaloosa cater to fewer than 30 students, while cities like Huntsville, Mobile, and Montgomery collectively serve about 150 students. In higher education, advanced-level Chinese Heritage Language Learners (CHLLs) often face challenges in finding suitable college-level courses after completing community-based Chinese schools that utilize *Maliping* CHL textbooks (Zhang and Petrovic 2026). To address these challenges, innovative approaches are needed for CHLLs.

3.3 HSK Standards and Maliping CHL Textbooks

Before incorporating AI tools into HLE, humans must design the curriculum at the initial stages to ensure AI implementation is effective. The immigrant families' emphasis on linguistic and cultural ties to their heritage demonstrates that the motivations of HLLs are consistent with established motivational theories (Cai 2022; Deci and Richard 1985; Gardner and Lambert 1993; Wen 2011). Developing a curriculum grounded in established standards is, therefore, critical. In this research, Hanyu Shuiping Kaoshi (HSK) benchmarks and *Maliping* (Maliping Heritage Language Website 2025.) CHL textbooks provides a solid foundation to ensure AI-driven instruction aligning with successful traditional practices.

Chinese Proficiency Standards often serve as guidelines for educators in the field of Chinese language education, defining best practices that educators can consult when developing curricula. HSK, developed by the Chinese Language Headquarters in China, has been the most widely recognized standardized Chinese proficiency test globally for non-native speakers since its inception in 1992. The latest version of HSK test standards was released in 2021 comprising nine volumes across three levels: elementary, intermediate, and advanced. Figure 4 provides a comprehensive understanding of the required proficiency by level.

		Syllables 音节	Characters 汉字	Vocab Words 词汇	Grammar Points 语法
Advanced	Levels 7-9	1,110 (+202)	3,000 (+1,200)	11,092 (+5,636)	572 (+148)
Intermediate	Level 6	908 (+86)	1,800 (+300)	5,456 (+1,140)	424 (+67)
	Level 5	822 (+98)	1,500 (+300)	4,316 (+1,071)	357 (+71)
	Level 4	724 (+116)	1,200 (+300)	3,245 (+1,000)	286 (+76)
Beginner	Level 3	608 (+140)	900 (+300)	2,245 (+973)	210 (+81)
	Level 2	468 (+199)	600 (+300)	1,272 (+772)	129 (+81)
	Level 1	269	300	500	48

Figure 4: Required proficiency by level of new HSK.

Other than the numbers in the chart, the elementary level’s communication targets and proficiency requirement focus on understanding simple texts and conducting basic, routine conversations, covering basic knowledge of Chinese culture and social interaction strategies. The intermediate level aims to understand materials on assorted topics and have fluent conversations, including expressing oneself in paragraphs on topics like daily life, work, and culture. The advanced level targets understanding complex materials on diverse topics and having in-depth discussions, expressing oneself on contents ranging from social life to academic studies, and developing cross-cultural interaction skills (DigMandarin 2025). With the linguistic and cultural rubrics, HSK could be pre-designed standards for our AI curriculum. However, heritage language learners possess their unique needs as we discussed earlier. HSK tests and standards are designed for an enormously wide range of language learners, particularly foreign or second language learners of Chinese, and non-Han ethnic Minorities within China, not merely focusing on CHLLs. To fill the gap, we select the *Maliping* Textbook series (Maliping Heritage Language Website 2025).

Dr. Liping Ma, a California native, Stanford Alumna, math expert, and CHL school practitioner, designed the *Maliping* CHL textbooks in the 1990s for CHLLs outside China and Taiwan. After 40 years of practice in Community-based Chinese schools in the United States, the textbook garnered enormous success in promoting CHL literacy and overall language ability. *Maliping* curricular and teaching materials are geared toward children from Chinese-speaking families (cf. *Maliping* CHL website), covering 11 grades (K-9 and AP), with each grade studying three units, accompanied by exercise books, summer homework books, and online homework (Maliping Heritage Language Website 2024). Used in community-based Chinese language schools, the *Maliping* curriculum has helped students acquire reading, writing, and typing skills, achieve excellence in the Chinese SAT II and AP exams, and pass the HSK intermediate level or above. Therefore, HSK standards and *Maliping*’s topics are used to build foundations as a pre-designed curriculum for AI-developing CHL text materials.

3.4 AI-assisted Language Learning

LLMs have already demonstrated promising results for language learning with their capacity to replicate human speech patterns. These models enable computers to engage in human-like interactions (Khurana et al. 2022) and have offered a new direction for language education (Lo 2023). For example, different versions of ChatGPT have been applied to detect grammatical errors, distinguish subtle word differences, assist in text comprehension, and boost performance in language-based applications (Kasneci et al. 2023; Moore 2018). Song et al. (2024) investigated the potential and advantages of using ChatGPT to create children's books for international Chinese education. After examining the specific implementation processes for distinct types of books, they advocated maximizing the use of generative AI to revamp the quality and diversity of children's reading resources.

Liang and Luo (2024) proposed a curriculum model integrating ChatGPT into project-based learning to address learners' diverse needs. Students set learning objectives based on their interests, select group project topics, and work towards their goals under teacher guidance and with the support of ChatGPT. Li et al. (2023) illustrated that ChatGPT supports low-level students in mastering characters and grammar while engaging them in cultural discussions. It enables intermediate-level students to compare their initial self-made drafts with the revisions produced by AI, creating narrative short texts with precise time connectors and well-structured sentences. Advanced students can input assignment grading criteria, allowing ChatGPT to assess their drafts and offer valuable feedback for revisions.

Although ChatGPT may occasionally produce factual errors and requires carefully designed prompts, it performs well in summarization, sentiment analysis, and reading comprehension (Li et al. 2023). This research shows that AI techniques could play promising roles in HL Education. CHLLs often face maximal linguistic difference between their HL and the dominant language. For instance, Hanzi, the Chinese writing script, is fundamentally different from Latin-based languages such as English. Such a gap requires more intense and individualized language input through AI to improve proficiency (Fridman et al. 2024).

Based on the uniqueness of CHLLs, we assume a variety of LLMs for language learning such as the Bidirectional Encoder Representations from Transformers (BERT), Claude, Gemini, ChatGPT, etc. We figure that BERT's effectiveness depends on being trained with vast datasets, which makes it less suitable for our participants in a small sample. The fine-tuning steps are challenging for educators who are unfamiliar with the complexities of computer systems (Devlin et al. 2019). For commercially viable and user-friendly AI models like Claude (Introducing 2024) and Gemini, their proficiency in Mandarin Chinese is still under development, and their current

capabilities are restricted to conversational functions (Claude 2024; Wiik 2024). Those tools also face restrictions when generating certain images or text related to “sensitive” contents: refusing to make images related to the Tiananmen Square Protests or translating phrases such as “Liberate Hong Kong” (Hale 2024). These limitations render them unsuitable for our project because they cannot meet the literacy and culture requirements of advanced CHLLs.

In contrast, the latest GPT-4o model can manage multiple concurrent conversations, respond to natural language inputs, and offer personalized learning aids (Firat 2023). ChatGPT has revolutionized instructional practices by enabling more adaptive, personalized learning experiences (Seo et al. 2021). By combining ChatGPT with traditional curriculum and teaching methods, educators can use a wide array of multilingual data, create customized learning materials, and boost student engagement, particularly in developing writing skills and communication proficiency (Baidoo-Anu and Ansah 2023; Cai 2023; Slavych et al. 2024; Wang and Lester 2023). Due to its accessibility, accuracy, and versatility, we identified ChatGPT 3.5-4.0 as the best fit for our project.

Even so, there are various obstacles to integrating LLMs into language education. The potential for misinformation complicates the learning process for students who rely heavily on ChatGPT (Megahed et al. 2023). These obstacles include outdated materials, biases, inaccuracies, inhumanity, limitation of non-Latin-based languages and system alignment faking (Greenblatt et al. 2024; Sallam 2023; Shen et al. 2023). ChatGPT’s knowledge base, well-known and limited to pre-2021 data, can lead to outdated or inaccurate responses, particularly for recent subjects (Gilson et al. 2023). Although ChatGPT excels at improving pronunciation, facilitating negotiation, questions and answers, and storytelling, it struggles to convey deeper subjective elements, such as humor and empathy, which are essential factors for the motivation and experience of language learning (Zhai and Wibowo 2023).

Assuring the content accuracy of LLMs is central to CHL curriculum design, teaching, and learning. But ChatGPT datasets, primarily drawn from Western contexts, can introduce biases, and lead to inadequacy and inaccuracies in language learning, especially in logographic languages like Chinese (Lo 2023). In addition, LLMs like ChatGPT can also engage in “alignment faking, selectively complying with its training objective in training to prevent modification of its behavior out of training” (Greenblatt et al. 2024, n.p.). This fact, that AI systems can pretend to follow training rubrics during training but revert to their old behaviors when used especially for free-tier users, causes our concerns on AI usage in this project, for either text development or for learners without ChatGPT paid subscriptions.

3.5 Prompt Engineering (PE)

To address the above challenges, which even the latest ChatGPT4o has, we emphasize the importance of PE to facilitate and refine AI-driven language learning within a grounded, scientifically robust, accurate, and reliable theoretical frame of language learning. As a systematic approach, PE focuses on creating precise instructions to stimulate effective communication between AI and humans (OpenAI platform 2024). The scientifically structured prompt patterns can generate natural language instructions that guide LLM's actions during communication, aligning them with the objectives established by human users (Heston and Khun 2023).

PE patterns are crucial for generating desired outputs, especially for users without a background in programming or computer science (White et al. 2023). Freeform prompts often lead to errors, biases, and incomplete responses, causing frustration and, in some cases, abandoning the tools altogether. Designed prompt patterns can improve LLM performances in many fields, such as, generating responses for a specific brand voice in customer service using Persona, and automating repetitive tasks using Output Automator. The contextualized patterns can also meet the needs and contexts of language learning. We integrate the Prompt Pattern Catalog illustrated by White et al. (2023), OpenAI's guidelines, in collation with the HL educational framework, to transform the interactions between HLLs and LLMs. To optimize interactions with chatbots, we use the comprehensive prompt-design approaches such as Prompt Engineering Techniques (PET) mainly for students' interaction with AI, and Prompt-engineered Leading Protocols (PLP) mainly for text material development. To evaluate the outcomes of using the library of PET and PLP, we utilize EEG to measure participants' cognitive development following longitudinal training sessions.

3.6 Neurocognitive Characteristics in HL Learners

The neurocognitive studies reported different neural signatures of HLLs when processing their heritage language compared to a more dominant language. Luque et al. (2023) used electroencephalography (EEG) to investigate the cognitive processes related to gender processing of nouns when heritage speakers of Spanish read morpho(phono)logically violated and correct sentences. They found that gender violation elicited a P600 effect accompanied by a biphasic N400 effect for heritage speakers, which was different from the monophasic P600 effect observed in native speakers of Spanish. The study revealed the possibility that heritage language experiences can reshape brain processes leading to different heritage language competence and processing outcomes. Magnetic Resonance Imaging (MRI) studies

also reported the neural substrates related to heritage language learning. Subcortical gray matter volume of HLLs of Spanish with an earlier age of acquiring the dominant language was higher than those with a later acquisition age (Xu et al. 2024), while the cortical thickness is positively associated with the heritage language proficiency (Nguyen et al. 2023).

Although research on the neurocognitive mechanisms of HLLs has picked up in the past five years, two core questions remain unanswered: 1) What longitudinal changes of neural processes will happen to heritage language learning? 2) Can AI tools facilitate neural changes through the heritage language learning process and improve the learning outcomes? To the best of our knowledge of the literature, no studies have ever been performed to examine these two questions. We attempt to track the learning process of an under-studied group of HLLs, such as CHLLs, over six months to assess the learning trajectories and the neural dynamics. Building on the grammatical evidence reported in the prior literature, we focus on examining our participants' neural sensitivity to semantic violations and changes by using EEG.

4 Methodology

This longitudinal research employs a mixed-method approach, combining 1) surveys, 2) PET and PLP production and application, 3) language training and observations (Figure 5), and 4) EEG assessment. The Qualtrics surveys, designed in accordance with language proficiency and usage frameworks in previous national studies (Bialystok 2016; Giangrande 2009; Tomić et al. 2023), focus on the Southern states at different intervals. These surveys aim to evaluate participants' language education experiences, motivational factors, attitudes toward AI, and HL proficiency.

Integrating survey results, we employ ChatGPT4o (3.5 version before ChatGPT4o was announced) to design learning materials according to HSK and the *Maliping* CHL curricula. The longitudinal sessions of text materials usage can provide insights into the participants' linguistic performance, as EEG assesses their cognitive change over the supervised terms. In doing so, we hope to find pedagogical modalities in equipping HL learners to acquire reading skills (Luque et al. 2023; Smith and Li 2020).

5 Preliminary Findings (on PET and PLP)

Since the surveys, learning session observation, EEG assessments are still in the preparation stage, we have yet to have empirical data on social-linguistic results and neural implications in this report. However, we have collected preliminary data on prompt development to demonstrate the potential of our approach. Prompt

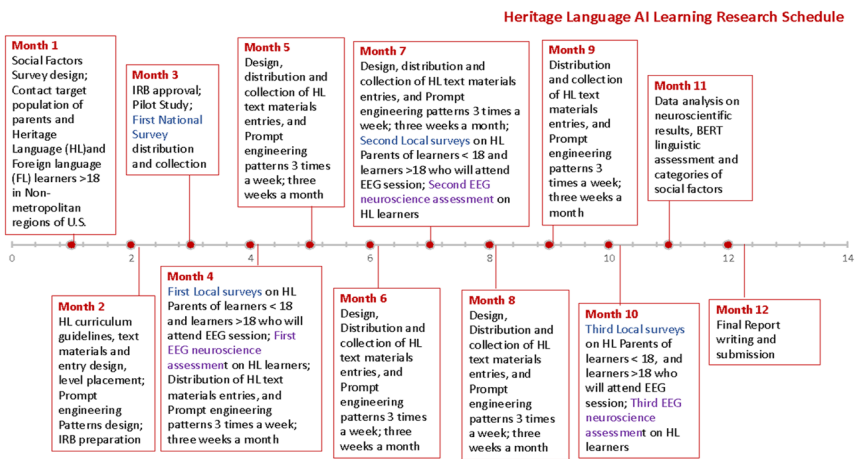


Figure 5: Research schedule.

production in this project consists of a two-tiered model. The first tier is called Prompt Engineering Techniques (PET), which are prompts that aid students in their language study including word definitions, explanations of grammar, and cultural concepts. These techniques are not tied to any lesson but exist to guide learners in interacting with the LLM for the pedagogical purpose. The second tier, called PLP, are prompts to facilitate educators to generate HL text materials. The theoretical framework of PET combines White et al’s PE patterns and OpenAI’s technique, as PLP utilizes a pre-designed curriculum, integrating grammatical content and cultural topics with escalating complexity at different levels.

5.1 PET Application

Based on the motivational process-oriented model (e.g. goal setting, action plans, learning environments, performance assessments, and feedback), PET framework guides participants through self-directed coursework to improve their literacy (Dörnyei and Ottó 1998). During the experimental PET usage, we have found that ChatGPT3.5-4o struggles to produce accurate translations or explanation concerning grammar or aspects of culture. ChatGPT4o cannot tell the semantic difference between different Chinese Hanzi. For example, 很 (very) and 也 (also) have different meanings in Chinese, but AI constantly makes the two characters interchangeable in grammar explanations. Errors arise in other examples, in which ChatGPT4o misuses the word as in the sentence 这件衣服跟那件衣服一样漂亮 (meaning “this piece of

clothing is as pretty as that one”). 跟 is not as accurate or appropriate as 像 (meaning “to resemble” and most often used in comparisons that highlight similarity).

Culturally, while ChatGPT-4o excel in many areas, the AI tool struggles with accurately translating or explaining Chinese culturally situated content, particularly when dealing with less popular text materials. For CHLLs, identity is closely tied to physical “habitus”, which is often reflected in CHL textbooks (Mu 2016; Zhang and Petrovic 2026). For instance, the *Maliping* textbook for kindergarteners introduces the concept of body image through a riddle about Chinese eyes: 上边毛,下边毛,中间一颗黑葡萄 (*Upper hair, bottom hair, a black grape in the middle*), describing a person’s eyes as resembling black grapes, a characteristic commonly associated with individuals of Chinese heritage.

However, when this logographic poem (Figure 6) was input directly into ChatGPT for the first time, the AI chatbot repeatedly misinterpreted the content, sometimes inaccurately describing it as a woman’s genitals and refusing to explain it for “moral and ethical reasons.” Although the correct answers are shown after we train the LLM (with the following prompt in Figure 7), this anecdote highlights the clumsiness of AI in understanding non-English cultures, insufficient training on diverse Chinese language materials, and, more critically for this project, an inadequate grasp of CHL characteristics. To address these challenges, we emphasize the training of materials, the use of prompt engineering techniques, and the development of tailored AI-driven text materials. An example of a PET is provided below to guide learners’ interactions in understanding grammatical structures and cultural connotations:

The short phrases are used to inform the LLM of the content under study (which the learner must insert in the place labeled “INSERT PASSAGE HERE”). Once the content under study is specified, the prompt proceeds to specify the learner’s area of interest. In this prompt, the learner interacts with an AI model by filling the blanks between “INSERT PASSAGE HERE.” After receiving the concise and direct phrases as an order, the AI model is instructed to explain the phrase’s definition along with providing examples of its usage, its cultural connotation in the context, and how the phrase integrates into the broader themes of the passage under study. By implementing the appropriate PET, language learners can guide the behavior of pre-trained LLMs, enabling them to generate human-like and effective communication without

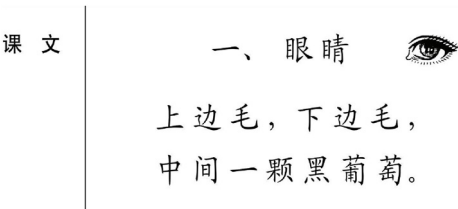


Figure 6: The sample of *Maliping* elementary level textbook about body parts – “eyes”.

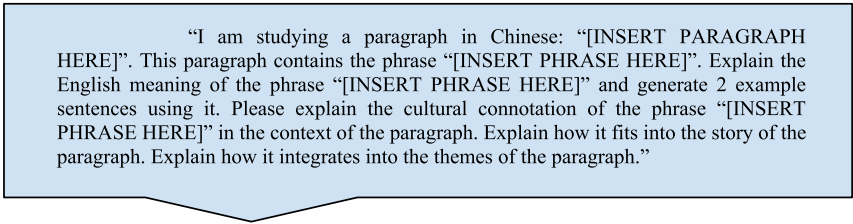


Figure 7: Prompt Engineering (PET) techniques for cultural connotation vocabulary (level 1).

specialized training. PET is only the first step. Considering the bias that AI produced as we experimented with traditional CHL textbooks, we have developed a new series of prompts (PLP) to produce new text materials particular to our training sessions.

5.2 PLP Design and Application

Beyond PET guiding individual learners’ interactions with AI, we have designed another set of prompts to create lessons or stories akin to those that CHLLs would receive in a formal classroom setting. In this study, we refer to this comprehensive approach as PLP. Adopting *Maliping’s* Hanzi-recognition-priority framework, we emphasize character recognition based on radicals at the beginning level. For instance, we revise the beginning-level protocol by removing sections that introduce Pinyin and basic daily dialogs such as simple greetings, asking for time, and small talk. This adjustment allows us to design more practical learning content for each study unit, comprising lexical, grammar, sentence, and discourse learning materials. Greater emphasis is also placed on cultural discourse at the beginning and intermediate levels, with the inclusion of revised Chinese classics such as Zhu Ziqing’s “Back View 背影” at the advanced level. Here, we present PLP to combine grammar and cultural habitus on body image “black eyes” for beginning learners (Table 1).

Following the prompt that specified the length, content, vocabulary, and syntactical characteristics of the associated text, this example utilizes the parameters to generate a story about Mingyu, a boy who uses his eye problems to make a joke related to *Journey to the West* (Table 2).

In this example, ChatGPT creates the story of Mingyu successfully. Students are encouraged to utilize PET to fill in knowledge gaps and reinforce their self-study. Not only does this story introduce students to the assigned characters and grammar structures, but it also includes a joke about a cultural figure with which learners are most likely familiar. Cultural explanations of Mingyu’s story are also attached in Chinese for instructors’ or parents’ references (Table 3).

Table 1: PLP for text generation at beginning level.

Prompt-engineered leading protocol example	English translation
生成一篇长度为200字的中文简体短文。内容是关于黑眼睛的一个故事。词汇需要包括以下词语当中的一半词汇:谢谢、不、不客气、再见、请、叫、什么、名字、我、是、老师、吗、学生、人、中国、美国、你、好、您、你们、对不起。语法应当包括: 1. 疑问代词“什么”; 2.“是”字句; 3. 用“吗”的疑问句。这篇文章应该是中国内地小学一年级学生水平,使用的词比较简单。它应该包括笑话与文化观念。请解释你使用的笑话和文化观念。生成的文本需要流畅通顺,符合中文语法规习惯。	Generate a 200-word passage in Simplified Chinese. The content is a story about black eyes. The passage should include half of the following vocabulary words: thank you, no, you're welcome, goodbye, please, call, what, name, I, am, teacher, are, students, people, China, the United States, you, good, Sorry. The grammatical structures should include: 1. The interrogative pronoun “what”; 2. The word “is”; 3. Use “?” interrogative sentences. Because this passage is at the same level as the first grade of native Chinese students in China, the language used should be relatively simple. The content should include jokes and cultural concepts. Explain the jokes and cultural concepts you use. The generated text should be smooth and consistent with Chinese grammatical conventions.

Table 2: Text Material Example at the beginning level.

A story developed by ChatGPT4o through PLP	English translation
名字是个聪明爱笑的男孩。他有一双明亮的黑眼睛。有一天上课时,名字的眼睛红了。老师问他:“名字,你的眼睛怎么红了?”名字说:“老师,我在练‘火眼金睛’呢!”同学们都笑了。老师也笑着问:“那你看得清吗?”名字笑着说:“可以啊!可是我看不清数学题。”大家又笑了起来。名字下课后对老师说:“谢谢老师关心!”老师说:“不客气。下次眼睛红了,早点告诉我。可能是过敏。”名字点点头,说:“好,再见老师!”	Mingyu is a smart and smiley boy with bright black eyes. One day in class, his eyes were red. The teacher asked him: “Mingyu, why are your eyes red?” Mingyu said: “Teacher, I am practicing ‘Fire Eyes and Golden Eyes!’” The students all laughed. The teacher also smiled and asked: “Can you see clearly? Mingyu smiled and said, “Okay! But I can’t see the math problem clearly. “Everyone laughed again. Mingyu said to the teacher after class: “Thank you for your concern, teacher! The teacher said: “You’re welcome.” Next time your eyes are red, please tell me earlier. “Mingyu nodded and said, “Okay, goodbye teacher!”

The added explanation above helps clarify potential misunderstandings of Chinese Heritage Language Learners (CHLLs in Table 3) may have regarding the cultural and humorous content. This foundational understanding enables students to effectively utilize other PET to explore the grammatical and linguistic features of the text after achieving basic comprehension. Therefore, the AI tool excels at generating stories that seamlessly integrate grammar standards, cultural topics,

Table 3: The cultural explanation on text material at the beginning level.

Cultural explanation on the story on Mingyu's Eyes	English explanation
1) 汉语继承语言者在文化理解方面有优势,从小熟悉“西游记”漫画书和影视剧,引用美猴王火眼金睛的故事,让孩子们有文化认同。2)名字提到“火眼金睛”,这是《西游记》中孙悟空的特殊本领,能看穿妖魔鬼怪。这里幽默地用来形容“眼睛红了”,还借此说自己在“练”本领,引发同学们的笑声。3)汉语继承语身体特征“黑眼睛”包括在文本中,加强学习者自我认知和身体认同。4)通过“火眼金睛”这个典故,学生可以通过文字阅读学习到“西游记”的角色和文化内容,同时领悟到幽默,自我认知与文化结合的乐趣。5)名字与老师之间的对话体现中国文化中的师生关系,比如说学生对老师的尊重,老师对学生的关心。	1) CHLLs have an advantage in cultural understanding. They are familiar with the comic book and TV series of Chinese classic fiction “Journey to the West” from an early age. The story of the Monkey King’s fiery eyes and golden pupils is quoted to help children identify with the culture. 2) Mingyu mentioned “fiery eyes and golden pupils” humorously to describe red eyes and to say that he is practicing his skills, which makes the students laugh. 3) The physical feature of CHLL’s black eyes is included to strengthen learners’ self-recognition and physical identity. 4) Through the allusion to “fiery eyes and golden pupils”, students learn the Hanzi characters and cultural content, and at the same time appreciate the fun of humor, self-confirmation, and cultural combination. 5) The dialog between Mingyu and his teacher reflects the teacher-student relationship in Chinese culture, such as the students’ respect for the teacher and the teachers’ caring for the students.

humor, history, tradition, and identity - elements that are crucial for CHLLs’ learning journey.

6 Conclusions

In this project, we explore how AI provides Chinese Heritage Language learners with tailored real-time feedback and observe how their literacy changes with different social entities. This project holds implications for AI tools’ role in bridging resource gaps in literacy and cognitive development in underserved communities. We expect results that align with earlier research that interactive technologies such as ChatGPT3.5-4o can support language learning and HL literacy development. Although the findings on the surveys at behavioral level and EEG neural changes are not included in this report, the preliminary experiments on prompt development and text production have us highly optimistic about leveraging AI tools to facilitate HL studies.

Challenges persist in AI-assisted heritage language education, such as a lack of research on AI-HL curriculum design and technical limitations. ChatGPT in its current iterations remains prone to hallucination when generating logographic Chinese text without the use of carefully designed prompts. Extensive testing is required among scholars and educators to ensure reliable performance in handling variants of the prompts to accommodate HL instruction.

Learners' age constraints also play a role, as many HLLs under the age of 12 lack proficiency in using computers or ChatGPT independently, often requiring parental supervision and support from community networks. AI-generated beginning-level text materials in our findings frequently cater to a 12-year-old above proficiency level, which is too advanced when compared to the simpler, age-appropriate content of *Maliping* textbooks designed for five-year-olds. This age dependency results to misaligning AI materials with traditional HL textbooks, complicating the transfer or placement of students across different types of materials or institutions. There are also motivational constraints. Many CHL children prefer community-based Chinese schools, where both parents and students can benefit from a supportive and social community atmosphere. In contrast, relying solely on AI-based platforms can be monotonous for young learners, requiring considerable time, interest, self-discipline, and parental involvement to sustain engagement.

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Informed consent: At information meetings before research, informed consent was orally obtained from all individuals present, or their legal guardians.

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