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A review of technology-enhanced Chinese character teaching and learning in a digital context

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Abstract

The acquisition of Chinese characters has been widely acknowledged as challenging for learners of Chinese as a foreign language (CFL) due to their unique logographic nature and the time and effort involved. However, recent advancements in instructional technologies demonstrate a promising role in facilitating the teaching and learning of Chinese characters. This paper examines studies exploring technology-enhanced character teaching and learning (TECTL) through a systematic literature review of relevant publications produced between 2010 and 2021. The synthesized findings shed insights on the research undertaken in the TECTL field, identifying a focus on characters' component disassembling, re-assembling, and associations among orthography, semantics, and phonology. In addition, learners' perceptions toward the use of technology and the benefits of various types of technological tools are also discussed in detail. Implications for TECTL are also put forward for future pedagogical practice and exploration.

Introduction

According to Allen (2008), Lu et al. (2013), Mason and Zhang (2017), and Shen (2004), learning Chinese characters is extremely difficult for CFL students. At least three elements contribute to the difficulties: linguistic factors (Hsiung et al., 2017; Xu et al., 2013), pedagogical issues, and language policies (Zhan & Cheng, 2014). Linguistically speaking, the tones, stroke order, radicals, homophones, and the inconsistency of sound-meaning connection all present great challenges to CFL learners, in particular for those whose first language uses an alphabetic written system (Chen et al., 2013; Liu, 2021). Pedagogically, this challenge has been exacerbated by CFL teachers' different pedagogical beliefs regarding when and how characters should be introduced in the learning process with or without the help of the Chinese phonetic system of *Pinyin* (Zhan & Cheng, 2014). Deng (2009) claims that the co-existence of simplified and traditional character writing systems resulting from historical Chinese language policies can lead to frustration or stress among CFL learners.

In response to these challenges, many scholars have conducted empirical studies investigating the efficacy of TECTL. Although these studies help to better understand the technology's role in facilitating the acquisition of Chinese characters, the TECTL literature lacks a holistic picture of current findings on the key factors that may affect the effectiveness and integration of instructional technologies in CFL teaching and learning. This review will therefore provide a critical overview of the relationship between technology and Chinese character acquisition by identifying recent key developments in the TECTL studies and their implication for future research directions.

Literature Review

Although the aforementioned difficulties in the character learning process seem to be immense and unavoidable, rapid advancements in technology provide a promising opportunity for both teachers and learners (Tsai et al., 2012; Wen, 2018; Xu et al., 2020). Earlier empirical studies primarily focused on how multimedia instructional materials using different media (visual, audio, graphic, and text) lead to better learning outcomes and higher user satisfaction. Among them, stroke sequence animation is regarded as particularly useful in enhancing the student's orthographic knowledge and improving their character handwriting performance (Chung, 2008; Jin, 2003; Kuo & Hooper, 2004; Li, 1996; Zhu & Hong, 2005). A web-based Chinese handwriting system, such as by Tang et al. (2006), was also developed and used for character learning. The system combined technologies, such as databases, animations, and orthographic recognition, to provide automatic feedback and analysis to check various handwriting errors and give useful feedback to learners. More recently, with the development of mobile technologies, such as smartphones, iPads, and tablets, the benefits of these devices are explored, including how they can enrich CFL learners' character learning experience by creating a more adaptable, communicative, and interactive learning environment (Liu, 2013).

To the authors' knowledge, there is none or only a few systematic literature studies related to this topic in the existing databases. Therefore, a synthesis of the latest literature is needed to fill in a few gaps in the TECTL knowledge body for the following reasons: (a) Although previous studies reported on the experimental data that investigated the effectiveness of using multimedia and animation in teaching and learning of characters, they did not elaborate on the instructional rationales and cognitive learning mechanisms of the technological tools in relation to CFL learners' cognitive processing of character learning. This knowledge is vital for CFL teachers to develop their digital competence (Starkey, 2020) and to equip them for making informed decisions when selecting appropriate technological tools and then using them critically and reflectively in the process of character teaching; (b) In the existing literature, only the use of multimedia and animation were empirically examined, the discussion of mobile technologies were not supported by CFL learner-related empirical data; and (c) Since 2014, new technologies have emerged and more empirical studies conducted, hence an up-to-date synthesis of research findings is needed to include more types of TECTL technologies that can provide timely feedback, keyboard typing, augmented reality, and embodied interaction, such as digital assembly games, key image methods, and learning systems.

Research Questions

To bridge these gaps, the current study is thereby guided by the following research questions:

1. What has been researched in studies examining TECTL between 2010 and 2021?
2. What technologies have been investigated to facilitate character teaching and learning? What are their benefits?
3. What implications can be applied to TECTL?

Methodology

This review adopts a systematic approach to collect peer-reviewed articles reporting empirical TCFL/TCSL studies on TECTL from 2010 to 2021. Figure 1 shows the steps followed to retrieve the data. To expand the study, four databases were used to retrieve the relevant data, including Web of Science (WoS), Scopus, CNKI (China National Knowledge Infrastructure) in Mainland China, and TSSCI (Taiwan Social Sciences Citation Index) in Taiwan. Before carrying out the search, we studied the related TECTL literature and identified some key terms for the initial retrieval of data. A preliminary query was executed to extract the studies related to TECTL. After analysing the keywords used in these studies, we included further relevant keywords to the query to see if they helped increase the number of appropriate articles—they were included in the search if they did and eliminated if not. A final list of keywords for data query was confirmed (see

Appendix) and used for data retrieval at the end of December 2021; a total of 167 articles were retrieved. Digital technology innovation and development are evolving drastically; hence, a timeframe of 2010–2021 was applied to the data retrieval process.

The articles were then manually assessed according to exclusion criteria by reviewing titles, abstracts, keywords, and research methodologies. Articles that reported empirical research about the teaching and learning of Chinese characters to CFL learners using digital technology were included. To be classified as an empirical TECTL study, a publication must use CFL learners or teachers as its participants to collect data and have a clear description of systematic data collection and analysis. Excluded were non-empirical studies that discussed the integration of digital technology into the teaching of characters or that reported the educational design or development of a certain database, software, or applications but without using experimental data. This refining process resulted in 50 articles for further scrutiny. After reading the full text of each of the 50 articles, 12 were excluded from the collection because they did not focus on reporting the effects of digital technology on the teaching and learning of characters to L2 learners. The final result of this selection process was a collection of 38 reviewed articles.

Figure 1

Publication Identification and Selection Process
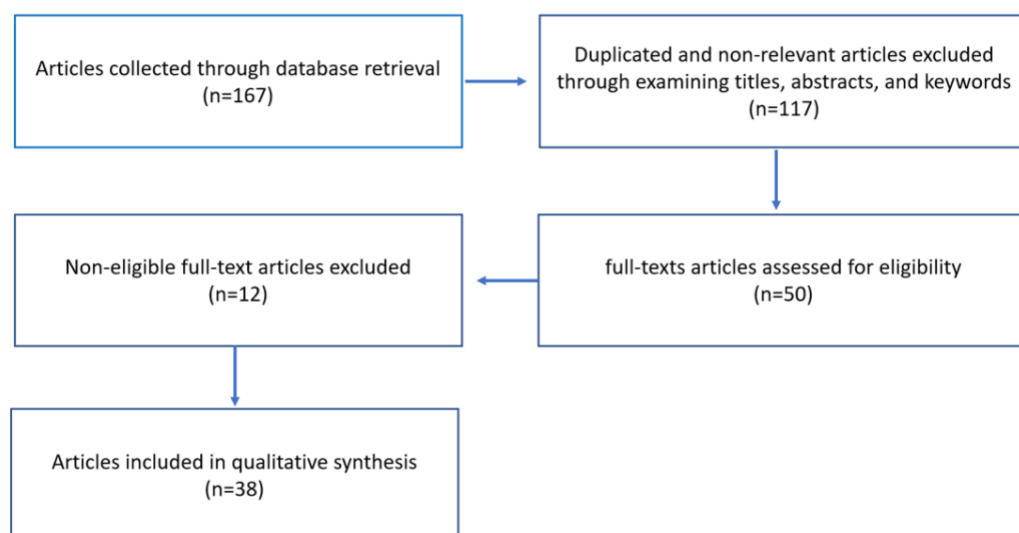
Following the methodology outlined by Braun and Clarke (2006), we undertook a thematic analysis of the content of the articles to establish latent themes. Coding nodes were created with the qualitative analysis software NVivo (version 12.60) while the researchers read through the full text of each article bearing in mind the aforementioned three research questions. Upon completion of this initial coding process, an NVivo Text Search Query was used to further develop the coding process by searching for salient recurring concepts and ideas discussed across the collected literature. The search results helped examine to what extent the concept was discussed and with what aspect of the character teaching and learning the idea was associated. The whole coding and analysis process was iterative, involving repeated reading of each study and continuously developing, refining, and testing any emerging and recurring patterns. To ensure the data analysis was reliable, the author and an experienced research assistant were involved with the coding process. After the data was coded independently, results were compared, inconsistent results were discussed,

and a final decision was made.

While the keywords used in the query for publications may have limited the number of papers that were retrieved for inclusion, the 38 studies do provide an international perspective of the latest research in TECTL, including Australia (1), Hong Kong SAR (1), Malaysia (4), Mainland China (4), Singapore (5), Taiwan (9), UK (4), and USA (10).

Findings

The analysis indicates that research in the past ten years has centered on five themes: technology-enhanced orthographic awareness development, technology-enhanced character recognition, technology-enhanced character production, learners' perceptions to the integration of technology, and the enhancing roles of instructional technologies in Chinese character acquisition.

Technology-enhanced Orthographic Awareness Development

Orthographic awareness has been defined as a metalinguistic awareness (Wong et al., 2013), referring to CFL learners' sensitivity to and understanding of the internal structure of characters and their ability to infer meaning and pronunciation (Lu et al., 2014; Tsai et al., 2012; Wang et al., 2003), and their awareness of "the principles of character structure and their ability to use this logical comprehension to learn characters" (Wong et al., 2013, p. 185). Three approaches to improving learners' orthographic awareness were identified (see Figure 2).

Firstly, orthographic awareness can be developed through a technology-enhanced multimodal character decomposing process. This structural decomposition can be accomplished by strategies such as viewing animations that display stroke-by-stroke writing sequences, and digital writing (i.e., writing on the screen of electronic devices, such as smartphones, iPads, writing pads that connect to computers, etc.) (Chang et al., 2015; Guan et al., 2011; Lu et al., 2014; Xu et al., 2013). Additionally, watching animated stroke writing sequences helped draw learners' attention to the internal visual-spatial configuration of the characters, thereby enhancing their understanding of the hierarchical structure and the relative position of each stroke within the character (Chang et al., 2015; Lu et al., 2014). Computer-assisted character handwriting or digital writing further facilitated learners to actively analyse and decompose a character's complete orthographic form and then recompose it from the bottom up, which in turn helped to establish a more precise and refined visual-orthographic representation (Xu et al., 2013). According to Guan et al. (2011) and Xu et al. (2013), digital writing practice can add motor-sensory information to characters' visual configuration, hence enriching learners' perceptual experience of the internal structural relationships.

The second approach to developing orthographic awareness is particularly beneficial for the learning of compound ideographic and phono-semantic characters which have either semantic or phonetic radicals as their components. It is a digitalized radical-derived character instruction characterized by focusing on the notion of radicals and making their learning an explicit process (Chen et al., 2013; Hong et al., 2016). This method greatly facilitates learners' acquisition of semantics, phonetics, and orthographic knowledge of Chinese characters. For instance, Chen et al. (2013) revealed that CFL learners benefited from being consciously taught to strategically use both the semantic and phonetic radicals simultaneously, which in turn facilitated a greater awareness of character composition. Likewise, using a digital composition game that based on the Chinese orthographic database developed by Chen et al. (2011), Hong et al. (2016) found it advantageous to help learners develop their awareness of the radical position regularity (some radicals frequently appear at some specific fixed positions within characters) so they can actively use the structure rules to assemble the correct characters when completing orthographizing tasks.

Figure 2

Technology-Enhanced Orthographic Awareness Development
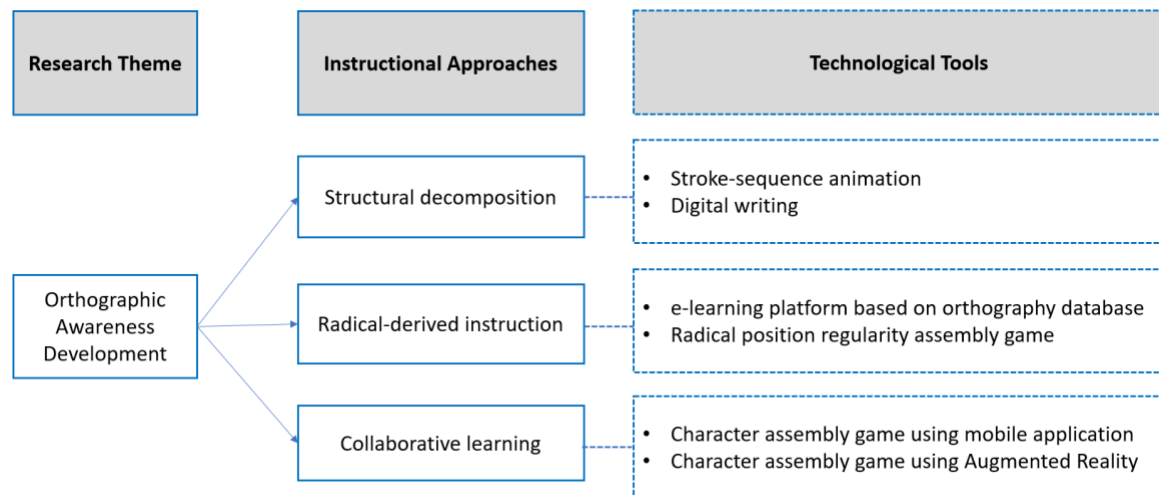
The third approach, which extends the second by including the collaborative and social aspects to the orthographic learning process, is a technology-enhanced collaborative learning model in a socio-constructivist context (Wen, 2018, 2019; Wong et al., 2011; Wong et al., 2013; Wong & Hsu, 2016). It endeavors to address the issue that many learning designs (such as Chuang & Ku, 2011; Hsieh & Fei, 2009) followed the principles of individualized instructivist and behaviorist learning and emphasized content memorization and retrieval, thereby neglecting the need for raising learners' in-depth orthographic awareness. Wong et al. (2013) subsequently designed a game called Chinese PP to strengthen the application of character structure rules using a mobile-assisted collaborative learning model. When playing the game in a classroom on mobile devices, learners must collaborate with their peers to assemble legitimate characters with different composition rules with randomly assigned radicals and components. From the social and collaborative perspective, this approach encourages learners to exercise their agency by actively participating in peer interaction while holding individual accountability for contributing to their groups' success (Wong et al., 2013). Similarly, Wen (2018, 2019) used a digital composition game with a paper interface called ARC (Augmented Reality-based Chinese Characters) in a classroom context. By playing a variety of character assembly activities in small groups, learners were cognitively helped to practice recognizing radicals and structures and to learn compound character construction rules.

Technology-enhanced Character Recognition

Previous studies recognize that a higher quality word representation is usually formed through establishing stronger interconnections among orthography, phonology, and semantics (Perfetti et al., 2005). Studies on character recognition, therefore, have primarily explored how technology enhances the establishment of robust bidirectional associations between the three elements (see Figure 3).

Figure 3

Technology-Enhanced Character Recognition
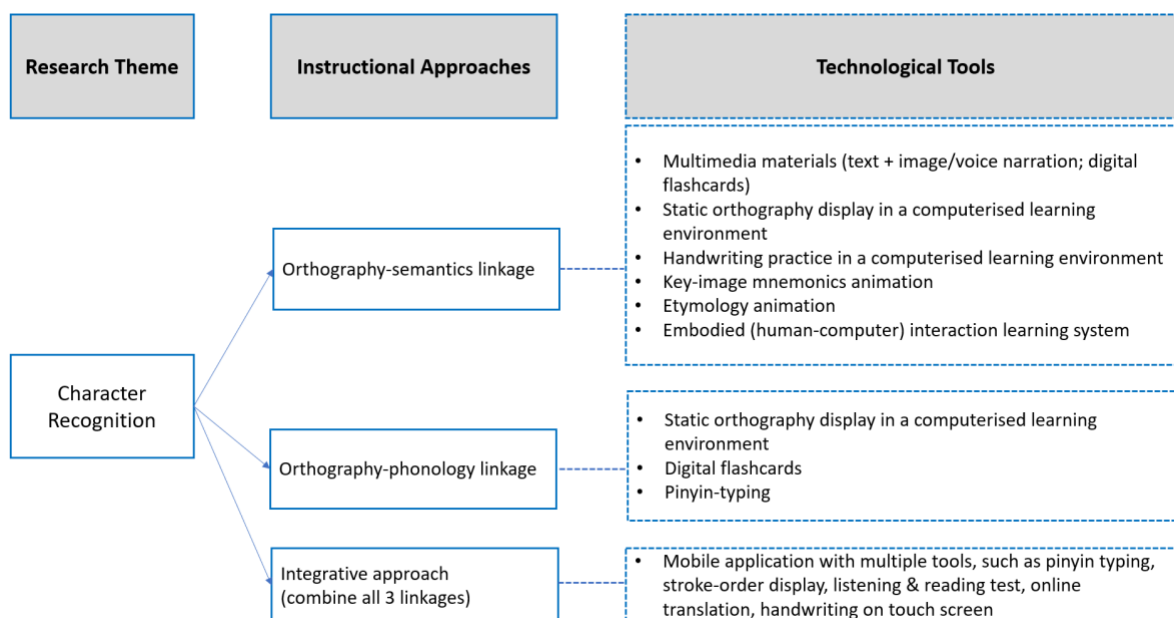
Establishing Orthography-Semantics Linkage

Orthography-semantics linkage has been identified as more reliable and useful than phonology-semantics linkage for CFL learners (Perfetti et al., 2005; Xu et al., 2013) because of the pervasive homophones among characters which cause competition between semantics patterns and phonological forms. Six ways to strengthen the orthography-semantics connection are identified: multimedia instruction, dynamic and static encoding, key-image mnemonics, etymology animation, and embodied interactions.

Firstly, multimedia instruction was found to have a greater positive effect on strengthening the link. Drawing on the dual coding theory (Paivio & Lambert, 1981) and the multimedia learning theory (Mayer, 2001), Zhu (2010) suggested that digital flashcards with orthography display and mnemonic text description, but without sound and stroke-order animation, were effective in this regard. Likewise, Chuang and Ku (2011) reported that on-screen text plus image and image plus narration could achieve the same effect.

Additionally, this linkage can be strengthened by either using dynamic or static encoding depending on the CFL learners' proficiency level. For beginners with little radical knowledge, handwriting compound characters in a computerised learning environment facilitated their learning of orthography by linking it to meaning translated from their L1 (Guan et al., 2011; Guan et al., 2015). For higher-level learners with advanced radical knowledge, viewing static orthography displays of compound characters in a computerised learning environment was found to be more effective than writing them by hand, since it allowed such individuals to allocate sufficient attention to both the holistic form of a character and its semantical radicals as clues and to make associated connections (Chang et al., 2015; Xu et al., 2013).

Two meaning-based approaches were the foci of four studies. Key-image mnemonics animation in Chang et al. (2019) and Chen et al. (2019) used animation to present the visual meaning cues showing form-meaning congruence, meaning that both are visually similar to the forms of characters and highly associable to their meaning. This strategy has the benefit of facilitating learners to build a stronger orthographic memory that binds form and meaning. In comparison, animated etymology in Chang et al. (2019) and He and Huang (2014) helped CFL learners strengthen the association by demonstrating the evolution of the

orthography over time and providing semantic cues that are more noticeable than in the earlier scripts. These two approaches were specifically beneficial for learning the logographic type of characters; the former was reported to be more effective for facilitating highly complex characters (Chang et al., 2019).

Lastly, muscular embodied interactions as a type of human-computer interactive system were also helpful in this regard because the physical movement was an extra modality to link visual orthography and semantics, thus reducing learners' cognitive load (Yang et al., 2017). This approach facilitated the conversion of the encoded information from short to long-term memory, in turn compensating for short-term memory loss (Xu & Ke, 2020).

Establishing and Strengthening the Orthography-Phonology Linkage

The establishment of the orthography-phonology linkage has been acknowledged as more difficult than that of orthography-semantics due to the arbitrary relation between a character's orthography and phonology (Guan et al., 2011; Shen, 2004). Consequently, the role of orthography-phonology linkage in character recognition has not been fully utilised in TECTL (Wang & Su, 2019). The review identified three ways to strengthen this linkage: viewing static orthography displays, digital flashcards with voice cues, and *Pinyin* typing. Similar to its role in connecting orthography and semantics, a static orthography display helped more advanced learners perform better in pronunciation recall tasks because it gave them more time to study orthography and its phonetic radicals and subsequently create links to pronunciation (Xu et al., 2013). Likewise, digital flashcards with sound and text, but without stroke-order animation, in Zhu (2010) were effective because they fully utilised learners' dual channel (auditory and visual) and dual coding processing (pure text info and text-image integrative within the visual channel). Additionally, *Pinyin*-based typing helped strengthen the linkage, as it successfully drew learners' attention to *Pinyin* segments and the tones of certain syllables and required learners to constantly identify and match characters to their phonological input (Guan et al., 2011; Guan et al., 2015).

The Integrative Approach

Different from the aforementioned studies that explicitly investigated the bidirectional linkages separately, four studies examined how bidirectional linkages benefit character recognition without separating them. For instance, using WhatsApp as an instrument, Chu and Toh (2014, 2015) found *Pinyin* typing can strengthen the three bidirectional linkages simultaneously. In their studies, learners were required to send messages to a group chat using *Pinyin* input. To accomplish the task, learners had to undergo a series of mental processes, including compartmentalizing a sentence into single characters, associating its orthography with its sound, typing the correct *Pinyin* to get a list of homophones, and lastly, choosing the correct characters from the list. By repeatedly going through such processes, learners were reinforced in associating the three lexical components and hence building strong connections between them. Similarly, Rosell-Aguillar and Kan (2015) and Qian et al. (2018) reported that learners benefited from using an integrated approach to learning character recognition with mobile applications and online learning resources, since it combined the use of stroke-order animation, *Pinyin* input and radicals, a listening test, reading test, English translation, and handwriting on a smartphone screen to reinforce the three bidirectional linkages.

Technology-enhanced Character Production

The acquisition of character production skills has been widely acknowledged as challenging for CFL learners, in particular for those from non-Sinosphere countries (Li, 2020). This difficulty is mainly caused by the tedious and time-consuming nature of repetitive copying and handwriting and the heavy workload for teachers to check the accuracy of writing individually and to provide timely and detailed feedback on the errors (Yang et al., 2017; Xu et al., 2020). Compared with character recognition which requires learners to acquire partial knowledge of all the characters' details, character production requires learners to have not only a complete knowledge of the character but also the capability to transfer the knowledge into motor

skills (Ke, 1996a).

The review revealed that using multimedia-assisted character writing instruction (Hsiao, 2015; Hsiung et al., 2017; Lu et al., 2014; Tin et al., 2018; Tsai et al., 2012; Xu et al., 2020) and improving the auto-evaluation of the quality of learners' character production are effective ways to improve CFL learners' character production skills (see Figure 4).

Multimedia-Assisted Character Writing Instruction

This approach emphasizes the benefits of combining dynamic visual encoding (such as view stroke animation), motor encoding (such as handwriting as a type of kinesthetic exercise) and providing personalized and prompt corrective feedback. While viewing stroke animation deepens learners' understanding of the building blocks of characters (Chang et al., 2015; Xu et al., 2013), it needs to be supplemented by a more robust motor encoding, such as handwriting practice, so that higher levels of orthographic learning which establish fully specified formation (including all strokes and radicals) can be promoted (Hsiung et al., 2017; Tsai et al., 2012). This can be achieved by providing learners with immediate, personalized corrective feedback through a computer-assisted remedial instruction system. Such types of systems help to avoid error fossilization, improve the quality of handwriting, and reduce the teacher's workload. The theoretically grounded multimedia handwriting system in Tsai et al. (2012), the Chinese character handwriting diagnosis and remedial instruction (CHDRI) system in Hsiao et al. (2015), the Key-image Mnemonics mobile application in Chen et al., 2019, and the interactive character learning system in Xu et al. (2020) all have the potential to impact on learners' character production skills positively.

Auto-Evaluation of Character Writing Quality

Improving the evaluation of learners' character writing quality is another way to enhance character production skills. The traditional method is a manual process which assesses learners' character composition using criteria such as accuracy (misplaced or wrong components), legibility (unproportioned or asymmetrical shapes), writing speed, and stroke order (Li et al., 2019; Tin et al., 2018; Zhang et al., 2007). This method, however, is often laborious and can have inconsistent results if carried out by different teachers. In addition, the feedback is often delayed, and learners' behavioral engagement with the feedback is often limited. Furthermore, some aspects of the writing process, such as stroke order, stroke directionality, and writing speed, are not available for teachers to assess when character production is assigned as homework. Lastly, the traditional evaluation is often quantity- and goal-oriented, meaning that learners often focus on the number of characters they can write and the approximate production of character orthography. This tends to lead them to ignore accuracy, the precision of character production, and awareness of the internal structure for the sake of expediency (Tsai et al., 2012).

Technology-enhanced character production learning systems, however, can automatically evaluate the writing quality by using various technological calculating and measuring algorithms. These systems are more quality- and process-oriented and can provide learners with immediate and personalized feedback regarding writing errors and specific and actionable help to correct errors. For example, the system in Tsai et al. (2012) can evaluate learners' character production by identifying various stroke and structural errors and does not let them proceed until a correct entry is completed. Similarly, the CHDIR system in Hsiao et al. (2015) evaluates users' writing quality by calculating the number of coordinates a learner-produced stroke passes through and whether it falls within the range of tolerable errors. Once detected, learners can correct their errors with the help of remedial multimedia materials. Likewise, the system in Xu et al. (2020) automatically rates learners' writing with six criteria regarding the number, type, location, order, direction, and resemblance of the strokes. Apart from the rating score, learners can replay the recorded writing process to identify their mistakes, which in turn improves their writing quality and reinforces their acquisition of character writing skills.

Figure 4

Technology-Enhanced Character Production
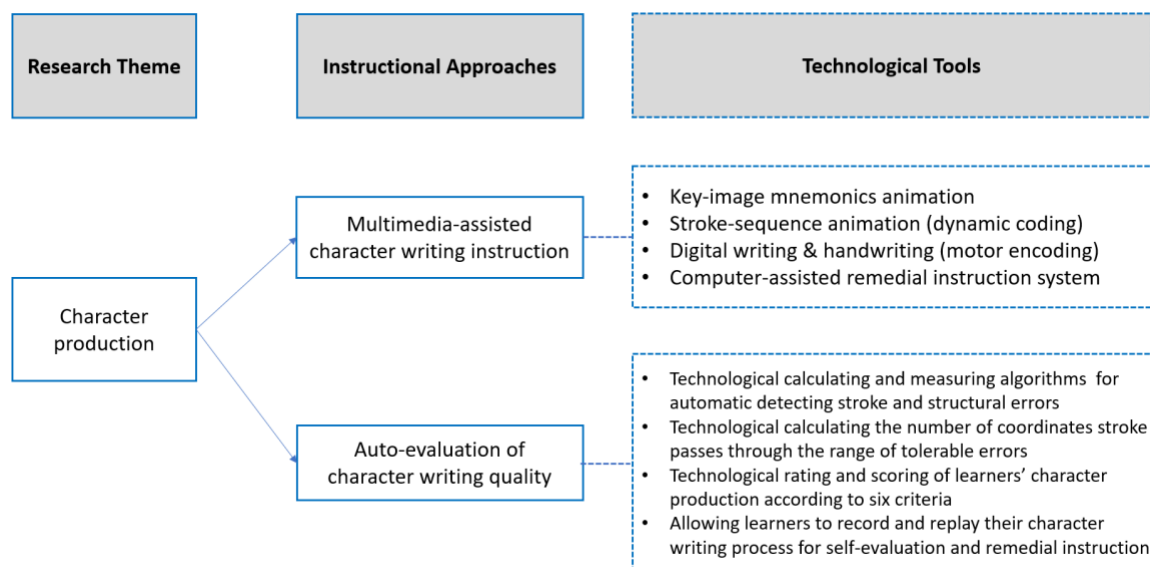
Learners' Perceptions to the Integration of Technology

Insights into learners' perceptions toward the use of technology in L2 learning have been widely recognized as beneficial in helping educators gain an in-depth understanding of learners' learning processes and to make informed decisions (Lee et al., 2019; Reychav & McHaney., 2017). Among the reviewed literature, approximately 47% of the studies reported learners' perceptions and attitudes toward the use of technology by gathering quantitative and qualitative data. Two salient sub-themes were identified: perceived usefulness and engagement.

Perceived Usefulness

CFL learners in a number of studies reported that the use of technology led to better learning outcomes by enhancing their cognitive processing, providing adaptive scaffolding, and facilitating collaborative learning. For instance, learners highly appreciated the pedagogical value of the use of visual and dynamic encoding methods in their character learning. This includes key-image mnemonics (Chang et al., 2019), etymological information (Chuang & Ku, 2011; He & Huang, 2014; Lu et al., 2013), and embodied interaction (Xu & Ke, 2020; Yang et al., 2017). These methods enabled learners to associate the abstract information with something more concrete and comprehensible by effectively reducing the cognitive load of their working memory.

Personalized timely feedback was highly regarded by learners as useful because it provided thorough and instantaneous adaptive scaffolding in their learning process, especially in the aspect of character production. This type of feedback is of great help for learners to identify their writing errors and misconceptions of character configuration. Additionally, it is beneficial when learners use the technologies in a self-paced learning environment because they do not have to wait for teachers to assess and provide feedback (Hsiao et al., 2015; Tsai et al., 2012; Xu et al., 2020).

Facilitating peer assistance and learning was perceived by learners as an advantage of game-based learning

activities (Wen, 2018, 2019; Wong & Hsu, 2016). Learners in Wen (2018, 2019) reported they enjoyed playing the component-based character composition game with group members using AR technology because they could learn from their peers and co-construct knowledge. Similarly, students in Wong and Hsu (2016) valued the use of the Chinese-PP game in their character learning as it helped them establish a positive game behavior of peer assistance.

Engagement

A positive attitude towards the technologies used for enhancing character learning in the reviewed literature was frequently connected with the highly engaging and motivating nature of some tools. Compared with traditional study methods, learning characters with these tools was regarded as more interesting and motivating, hence helpful in boosting their confidence. For instance, the novel method of embodied interaction has the advantage of using body movements to physically interact with learning materials, making the character learning experience more fun and enjoyable (Lu et al., 2013; Xu & Ke, 2020; Yang et al., 2017). In studies by Chen et al. (2019), Chuang and Ku (2011), and He and Huang (2014), the use of various types of visual aids helped stimulate learners' interest and consequently improved their learning performance while providing higher user satisfaction. Some pedagogical features offered by certain technological tools, such as positive reinforcement achieved by the badge mechanism in Wen (2018) and the rating system in Xu et al. (2020), were regarded by participants as motivating and rewarding. Participants in the Goh (2016), Lu et al. (2014), and Rosell-Aguillar and Kan (2015) studies enjoyed using mobile devices for character learning because of some of the drills and practice functions which were tangible, intuitive, and fun user interface, with a bite-sized learning approach and an easy access to rich and multimodal resources.

The Enhancing Roles of Instructional Technologies in Chinese Character Acquisition

In this section, we discuss the trends in the use of instructional technologies in TECTL. As can be seen in Table 1, the use of mobile applications has received the most attention, followed by multimedia learning, computer-assisted learning systems, eye-tracking, embodied interaction, and Augmented Reality (AR). The following discussion first summarizes the benefits of each type of these technologies, with a focus on the last three newly emergent technologies.

The review identified the two main benefits of mobile applications concerning character learning, namely the integration capacity and facilitation of collaborative learning—both well suited for transforming the learning of Chinese characters. Mobile applications can incorporate various learning tools to present the content in a variety of forms, such as audio, video, image, animation, game, dictionary, interactive activity, and personalized feedback in just one learning platform (Chang et al., 2019; Chu & Toh, 2015; Lu et al., 2014; Rosell-Aguilar & Kan, 2015). This gives learners the choice of their preferred learning styles to learn at their own pace. This particularly suits CFL learners to help establish the three bidirectional links by multiple input methods, such as touch screen *Pinyin* typing, voice recording, handwriting (Chu & Toh, 2014, 2015; Ting et al., 2020), composing characters with radicals or components (Wong et al., 2011; Wong et al., 2013; Wong & Hsu, 2016), word search in online dictionaries, and short quizzes for self-evaluating (Goh, 2016; Lu et al., 2014; Mason & Zhang, 2017; Qian et al., 2018; Rosell-Aguilar & Kan, 2015), to mention a few. The other advantage is their capacity to facilitate interactive, communicative, and collaborative learning by serving as an effective medium through which active learning can be achieved through learners working together and flexibly forming groups during the gaming process (Wong et al., 2011; Wong et al., 2013; Wong & Hsu, 2016).

Table 1

Instructional Technologies Used in the Literature Review

Technology	Number of Studies	Publications (first author only)
Mobile Application	12	Chen (2019), Chu (2014, 2015), Goh (2016), Ting (2020), Lu (2014), Mason (2017), Qian (2018), Rosell-Aguilar (2015), Ting (2020), Wong (2011), Wong (2013), Wong (2016)
Multimedia Learning (Including Animation)	10	Chang (2015), Chang (2019), Chen (2014), Chuang (2011), He (2014), Hsiung (2017), Liu (2021), Lu (2013), Xu (2013), Tin (2018), Zhu (2010)
Computer-assisted Learning	9	Chen (2013), Guan (2011), Guan (2015), Hong (2016), Hsiao (2015), Shei (2012), Tseng (2016), Xu (2020), Tsai (2012)
Eye-tracking Technology	3	Liu (2021), Stickler (2015), Wang (2019)
Embodied Interaction	2	Xu & Ke (2020), Yang (2017)
Augmented Reality (AR)	2	Wen (2018, 2019)

Nine studies explored the facilitating role of computer-assisted character learning systems, such as the CHDIR system (Hsiao et al., 2015), the CRAG e-learning system (Hong et al., 2016), the Interactive Chinese character learning system (Xu et al., 2020), Linkit (Shei & Hsieh, 2012), the Radical-derived Chinese character e-learning platform (Chen et al., 2013), and the Web-based Chinese Character Recognition Assessment system for Distance Education of Chinese (Tseng et al., 2016). Although these systems have a similar integration capacity to mobile applications, they do have some unique characteristics. For example, the device screens connected to these systems tend to be larger, which is more suitable for character writing learners; additionally, they may be more powerful to run various large databases, such as the Chinese orthography database (Chen et al., 2011), orthographic database (Hong et al., 2016), and sound and character database (Shei & Hsieh, 2012). It may be faster to process a large amount of data when learners retrieve and extract information from internal or external resources (Shei & Hsieh, 2012).

Multimedia learning, including animation technology, is capable of combining different media in instructional materials and practice activities, such as audio, visual, graphic, and text. The appropriate use of multimedia learning can effectively reduce CFL learners' cognitive load in their working memory by separating the information into two or more different channels, such as verbal and non-verbal information (Chen et al., 2014; Chuang & Ku, 2011; Liu, 2021; Tin et al., 2018; Zhu, 2010). Stroke order animation, one of the many types of multimedia learning, has the advantage of using dynamic encoding to direct learners' attention to characters' visual-spatial configuration, thereby enhancing their understanding of the structure and compositional details of characters (Chang et al., 2015; Guan et al., 2011; Lu et al., 2014). Stroke animation encourages implicit writing, resembling writing characters by hand but without the actual motor sensory input. This is a particularly practical and economical alternative approach to improving character orthographic recognition (Xu et al., 2013).

While eye-tracking technology has long been used for reading research, it is relatively new for facilitating

character learning (Stickler & Shi, 2015). It has been recognized to play a role in helping learners to create connections among orthography, semantics, and phonology (Liu, 2021; Stickler & Shi, 2015; Wang & Su, 2019). For instance, this technology can be used to reveal learners' real-time attention focus during task performance and report how it helps investigate the scaffolding role of *Pinyin* in reading and speaking and its confirming and consolidating role in associating orthography with phonology (Stickler & Shi, 2015). Eye-tracking data can also be used as a pedagogical tool, such as helping learners to reflect on their learning behaviors or for training teachers to deepen their understanding of learners' perspectives.

Embodied interaction has at least two advantages in facilitating character learning (Xu & Ke, 2020; Yang et al., 2017). First, it can associate specific body movements and/or gestures with certain pre-defined strokes or the meaning of characters. This can be achieved by integrating situated information, such as learners' imagination, sensation, active embodiment, structural configuration, and/or the concrete meaning of characters, into the learning process, which in turn may lead to better orthography writing performance or more accurate future meaning retrieval. Additionally, physical movement or gestures adds extra modality of information resources. This can help reduce the cognitive demand for storing information in working memory, hence transforming the character learning experience by reducing repetitive copying and writing and adding innovative and alternative approaches to orthographic acquisition.

AR is an emerging technology that can be used to facilitate character learning in a classroom environment (Wen, 2018, 2019). AR can combine real-world objects (paper cards with characters, radicals, or components printed on them) with virtual objects (assembly games with multimedia content such as audio, stroke sequence animation, and contextual information). The use of physical objects is not only cost-effective (such as low-cost paper cards) but also facilitates easy and intuitive interactions among learners when playing a variety of character assembling games. In addition, with a tangible paper interface, the augmented object has the benefit of providing immediate kinesthetic feedback, empowering learners to encode and organize information while improving their deep understanding of character structure, meaning, and recall. Digital assembling games can create multimedia, multimodal, and authentic contexts for character learning collaboratively, thus helping shift character learning from rote learning and mechanical practice to active learning and socio-cognitive interaction.

Conclusion and Implications

This systematic review found that TECTL studies between 2010 and 2021 have investigated five key areas, including technology-enhanced orthographic awareness development, character recognition, character production, learners' perceptions, and the enhancing roles of instructional technologies in Chinese character acquisition.

The development of orthographic awareness can be achieved through structural decomposition, radical-based instruction, and gamified collaborative learning. Establishing strong associations between form, meaning, and sound through technology is most effective in facilitating character recognition. Multimedia-assisted character instruction is effective in improving both the quality and accuracy of the handwriting of learners. Additionally, the automated evaluation of the quality of learners' handwriting seems to be a promising approach. Learners reported positive attitudes toward the use of technology in their learning and found the learning experience to be more enjoyable and motivating.

The affordances of six types of technologies - mobile applications, computer-assisted learning systems, multimedia learning, eye-tracking, embodied interaction, and Augmented Reality were also explored by the reviewed studies. Mobile applications and computer-assisted learning systems offer learners multiple input methods and facilitate interactive, communicative, and collaborative learning. Multimedia learning reduces cognitive load by presenting information in different channels. Eye-tracking technology helps create connections between orthography, semantics, and phonology, while embodied interaction associates body movements with pre-defined strokes or meanings. Augmented Reality combines real-world and virtual objects for a more immersive learning experience. The latter three, which are emerging, require

more empirical data to further validate their effectiveness in enhancing character acquisition.

The present findings have a few important implications for TECTL. Firstly, CFL teachers need to develop a solid knowledge base regarding the use of various types of technological tools for enhancing character acquisition. This could include an in-depth understanding of the instructional rationales and cognitive learning mechanisms and an evaluation of the suitability of specific tools for the teaching of certain aspects of Chinese characters to CFL learners at specific proficiency levels. For example, Key-image mnemonics animation is an effective means to help learners create a robust linkage between orthography and semantics through a systematic and dynamic form-meaning congruence which reduces the difficulty and complexity caused by the abstract relationship between the form and meaning of a character. However, this method, as Chang et al. (2019) pointed out, maybe most effective in facilitating the learning of logographic characters at the initial stage. The learning of other types of characters, such as compound phono-semantic, could be helped by the integration of other tools. Future studies could expand the investigation by including an exploration of the facilitating roles of technology in character acquisition at more advanced levels.

Pedagogically speaking, more effort is needed to further shift the exploring of the use of technology in TECTL from primarily investigating the effects of technology on enhancing cognitive processing and performance improvement to including social, collaborative, and affective factors. Given that empirical inquiries into the field of gamified character learning have recognized the importance of the socio-cognitive approach and that learners' engagement, motivation, and positivity play an important role in enhancing character learning, more work is needed to explore CFL learners' social and emotional needs as highlighted by Chang et al. (2019), Qian et al. (2018), and Wong et al. (2011). It is both vital and necessary for teachers to gain an in-depth understanding of the relationship between CFL learners' learning styles and their social interaction and collaboration, motivation, anxiety, emotion, agency, and other personal factors that are related to their Chinese character learning, so they can consider all these factors and consequently adopt appropriate and effective pedagogical approaches (Li, 2020).

Given the fact that CFL learners in general have very limited time to learn Chinese characters in formal classroom settings and that CFL teachers' workload increases if they are committed to providing individualized and instantaneous feedback to students, technology-enhanced personalized and timely learner-support is thus essential for CFL learners to improve their character learning performance and to maintain their motivation in an out-of-classroom or self-paced learning environment. CFL teachers can support learners by providing them with easy access to a computer-assisted learning system or mobile applications that can give automated evaluation and corrective feedback on their character production. Alternatively, they can work collaboratively to understand the functionalities of certain technological tools and how they can best be used for character learning. Learner support could be realized through teachers' development of new ways to observe learner behaviors through learner analytics or the effective use of learning management systems to carry out further inquiries to inform their learner-support-related decisions. Future studies could include this aspect to explore how support enhances Chinese character acquisition in a digitalized character learning environment.

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Appendix. Keywords for Data Query

The search string for query includes some broad keywords and some technology-related ones. The broad keywords include "Chinese as a Foreign Language (CFL)," "Chinese as a Second Language (CSL)," "Chinese character*," "Chinese radical*," "Chinese orthograph*," "character *writing," "stroke*order," and "stroke sequence." To identify studies that focus on TECTL, we used "interacti*," "animation," "e*learning," "multimedia," "comput*," "mobile," "technolog*," "database," "application*," "online," "typing," "game," "system," "CALL," "MALL," "digital*," "web," "corpus," "distance," and "Key-image." Some variant uses of these keywords were also added to the search string for retrieving data from CNKI and TSSCI. For example, 汉语国际教育(Teaching Chinese to Speakers of Other languages/TCSOL), 留学生(overseas students), 对外汉字(teaching characters to foreigners), 微课(micro-lecture), 微信(WeChat), 信息(information), 键盘(keyboard), 远程(distance), and APP are some high-frequency keywords used in TECTL studies in mainland China, while 華語為外語學習(Learning Chinese as a Foreign Language), 漢語作為第二語言學習(Learning Mandarin as a Second Language), 對外華語教學(Teaching Chinese as a Foreign Language), 遠距(distance), 應用程式(application) are some of the variant terms used in TSSCI in Taiwan.

About the Author

Michael Li is a senior lecturer in Chinese language at Massey University in New Zealand. His research focuses on the intersection of Teaching Chinese as a Second/Foreign Language (TCSL/TCFL) and instructional technology and design. Specifically, he specializes in second language acquisition in blended learning environments.

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