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USING A RADICAL-DERIVED CHARACTER E-LEARNING PLATFORM TO INCREASE LEARNER KNOWLEDGE OF CHINESE CHARACTERS

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The present study is aimed at investigating the effect of a radical-derived Chinese character teaching strategy on enhancing Chinese as a Foreign Language (CFL) learners' Chinese orthographic awareness. An e-learning teaching platform, based on statistical data from the Chinese Orthography Database Explorer (Chen, Chang, L.Y., Chou, Sung, & Chang, K.E., 2011), was established and used as an auxiliary teaching tool. A nonequivalent pretest-posttest quasi-experiment was conducted, with 129 Chinese-American CFL learners as participants (69 people in the experimental group and 60 people in the comparison group), to examine the effectiveness of the e-learning platform. After a three-week course—involving instruction on Chinese orthographic knowledge and at least seven phonetic/semantic radicals and their derivative characters per week—the experimental group performed significantly better than the comparison group on a phonetic radical awareness test, a semantic radical awareness test, as well as an orthography knowledge test.

Keywords: Chinese as a Foreign Language (CFL), Chinese Orthographic Awareness, Radical-Derived Character Instructional Method, Phonetic/Semantic Radicals

INTRODUCTION

The rise of China to international prominence in recent years has made learning Chinese extremely popular, and increasing numbers of non-native Chinese students have begun to choose Chinese as their second language of study. Though learners when learning a second language may attempt to apply techniques used when acquiring their first language (cf. Cook, 2003; Dulay, Burt, & Krashen, 1982; Larsen-Freeman & Long, 1991; Jiang, 2008), learners of Chinese who have alphabetic first languages tend to find Chinese writing difficult to learn. This is because in alphabetic writing systems, the orthography of a phrase typically has a specific relationship with its pronunciation, which is known as the grapheme-phoneme correspondence (GPC) rule. Chinese orthography, on the other hand, is logographic and composed of radicals in two-dimensional squares. As specific characters do not necessarily correspond to specific phonemes, one cannot know a character's pronunciation simply by observing its representation. International students or heritage Chinese learners whose learning strategies may rely on phonemes probably are accustomed to determining a word's pronunciation by simply reading the representation; thus, the absence of the GPC rule for Chinese characters may become one of the major obstacles when these students learn and memorize characters (Shi & Wan, 1998).[1]

Because Chinese character structure is so different from alphabetic words, it is highly recommended to incorporate multiple strategies when learning Chinese characters (Fan, 2003). Many researchers have focused on maximizing character learning (cf., Ho & Bryant, 1997; Huang & Hanley, 1994; Shen, 2005; Zheng, 2010). To tackle this learning challenge, some researchers suggest using radical-derived character learning strategies to increase character learning performance (Huang, 2006). *Radicals* are the minimal orthographic unit in Chinese writing. They can be as small as a stroke or as large as a semantic radical.

Many radicals are phonographic (e.g., 里 neighborhood, li3; 巴 cling to, ba1; 文 word, wen2)[2] or logographic (e.g., 虫 bug, hui3; 山 mountain, shan1; 金 gold, jing1). Those that are phonographic are also called phonetic radicals, and can serve as a pronunciation guide. Those that are logographic are called semantic radicals, and can suggest the meaning of the character. The radical-derived character learning strategy uses either a phonetic radical or a semantic radical to learn other words that are related derivations. For example, after learning the phonetic radical 里 (li3, neighborhood), learners are well-positioned to learn phonetically derived characters such as 俚 (li3, rustic), 浬 (li3, nautical mile), 哩 (li3, mile), 鋰 (li3, a kind of metal), 狸 (li2, fox), 裡 (li3, inside), 娌 (li3, sister-in-law), 理 (li3, reason), and 鯉 (li3, a kind of fish). After learning the semantic radical character 虫 (hui3, insect), learners are well-positioned to learn other semantically derived characters such as 蚊 (wen2, mosquito), 蛀 (zhu4, bore through), 蛆 (qu1, maggot), 蜂 (feng1, bee), 蛾 (e2, moth), 蝶 (die2, butterfly), 蝸 (gua1, snail), 蟻 (yi3, ant). In other words, by knowing one radical, one can learn a set of similar words, including phono-semantic compound characters.

The radical-derived character learning strategy is based on the principle of chunking (Gobert et al., 2001). A chunk is a collection of elements having strong associations with one another. In terms of radicals, common elements to be chunked can refer to either a phonetic radical or semantic radical, and their hierarchically lower derivative characters. Using chunking, learners can utilize familiar characters as a scaffold to memorize those they have not learned yet (Lu, 2000). Should learners be able to learn and use the radical-derived character learning rule, they will be able to understand most characters. Besides having the merits of chunking, the radical-derived character learning strategy also sheds light for the learner on different characteristics of Chinese orthography: configuration categories, radical position-based regularity, and stroke order (Yeh, Li, & Chen, 1999; Yeh, 2000). In terms of configuration categories—the different structures in which radicals can be combined spatially—Chinese characters, with square-shape features, can be categorized into at least eleven structures, which constrains the combinations of radicals (Chen et al., 2011). Then, in terms of position based-regularity, each derived character contains radicals that are usually displayed in certain positions within a certain configuration. Furthermore, stroke order means the radicals have specific sequences of strokes following a specific order in their written composition. Since instruction in radical-derived characters provides learners with hierarchical frameworks for characters which can be derived from identical radicals, it is somewhat easier for learners to observe the orthographic features. This orthographic knowledge can be delivered explicitly via teachers who use the radical-derived character teaching method.

However, previous research indicates that it is uncommon for CFL beginners to use phonetic components or semantic components when learning characters (Zhao & Jiang, 2002; Shen, 2005). In their investigation on strategies used by CFL beginners for learning characters, Zhao and Jiang (2002) indicated that the most traditionally used strategies are memorizing a character’s shape as a whole and writing a character mechanically; phonetic or semantic components were rarely used to learn characters. This was particularly the case with phonetic components. Some researchers suggest that the reason for this is that beginners have such a restricted vocabulary that they do not realize the importance of a character’s phonetic and semantic components. However, the longer learners study Chinese, the more frequently they can use phonetic and semantic components to make inferences about new words and phrases. This strategy works not only with CFL learners but also with learners whose first language is Chinese (Jiang, 2008; Shu & Zeng, 1996; Taylor & Taylor, 1990). Indeed, this pedagogical approach has become more and more popular for teaching Chinese as a first language (Huang, 2008).

This theoretical trajectory has been supported by empirical studies that have tested beginning adult

Chinese learners' sensitivity to the visual-orthographic structures of Chinese characters (Wang, Perfetti, & Liu, 2003), and others that have investigated the developmental radical awareness among adult nonnative learners of Chinese across learning levels (Shen, 2000; Shen & Ke, 2007). In line with this argument, Taft and Chung (1999) reasoned that the longer the learners study Chinese, the better they can use radical structures to facilitate learning. Moreover, Jackson, Everson, and Ke (2003) found that adult CFL students developed semantic radical awareness and were able to guess the meanings of unknown characters after one year of Chinese learning. Additionally, Liu et al. (2007) reported that adult CFL learners acquired orthographic representations of characters after one 15-wekk term of instruction (e.g., the learners could understand that 間 (jin1, between) and 問 (wen4, to ask) are orthographically similar), and further, that the learners displayed greater semantic and phonetic priming effects in Chinese naming tasks at the end of second term than at the end of first term. (i.e., the learners' reaction time is shorter when they see that the prime-target character pairs are semantically or phonetically related as opposed to their reaction time for unrelated pairs). For example, the learners respond faster when they see the semantic pairs, 姐 (ji3, sister) — 弟 (di4, brother), or the phonetic pairs,十 (shi2, ten) — 時 (shi2, time), than when they see unrelated pairs such as 馬 (m3, horse) — 弟 (di4, brother) or 小 (xio3, small) — 時 (shi2, time). These studies suggest that as the vocabulary size of CFL learners increases, the learners' Chinese orthographic knowledge expands.

In recent years, the field of education has become aware of the potential impact of computer technology on language learning, suggesting that computer technology is a useful compliment to teachers in assisting language acquisition (Jin, 2003, 2007); we propose three benefits of computer-assisted language instruction based on related empirical studies. First, computer technology provides interesting ways to represent learning content, thus motivating learners to get involved in language learning (Lin, Huang, & Chiang, 2009; Lu, Wu, Martin, & Shah, 2009). According to the dual coding theory (Clark & Paivio, 1991; Mayer & Moreno, 2002), when both visual and verbal information are presented to learners simultaneously, they are more motivated and have better recall of the learning materials compared to learners who receive only one mode of information. Thus, multiple coding should positively impact language learning. Second, instructors, when employing multimedia to deliver messages to learners, will have more diverse ways of presenting information. Moreover, as instructors enrich their lesson plans via digital technology, they can also offer prompt feedback to their students, without temporal or spatial restrictions. For instance, in a study that investigated how different instructional methods affect the learning process of character handwriting among beginning college level learners of Chinese, the learners wrote characters on digital writing tablets and then submitted them to a computer-assisted program (Tsai, Kuo, Horng, & Chen, 2012). When learners made a writing error, they received immediate feedback from the program and were forced to correct the error before continuing. The computer-assisted program improved the quality of the learners' character handwriting. Then too, as computer-based materials can be reused and work well for repetitive practice, they are well-suited for language learning (Wen, 2003). In contrast with traditional instruction, computer-assisted language learning approaches enable learners to select multimedia learning materials (e.g., reading, animations, or auditory explanations) that match their learning styles, to do repetitive practice, and to start a lesson anytime and anywhere. This approach can be quite student-centered.

Although there are many benefits of computer-assisted language instruction, little is known about the impact of combining a radical-based strategy with the use of multimedia in the classroom, a computer-assisted approach commonly believed to enhance language learning (Bush & Terry, 1997). One of the few studies on this was conducted by Jin (2003). In this study, multimedia was used to present three interfaces for memorizing characters to 120 U.S. college students learning Chinese at one Beijing summer school. The first interface used Hanyu pinyin[3] along with an English translation: as an example, the character 好 is presented on the computer screen with its pronunciation in Pinyin “ho3” and the English meaning, “good.” This provided students with both the phonetic and semantic information. The second interface used stroke animations showing the stroke-by-stroke sequence together with the phonetic and semantic information. The third interface also retained the phonetic and semantic information while including radicals and illustrations, displayed by means of video clips in order to introduce etymology, radicals, and orthographic rules. The display time for each character (36 characters in total) was limited to approximately five to eight seconds. Each student practiced learning the characters using the different computer interfaces, and then reported the characters individually to the experimenter. The recognition rate for characters was higher in the group using the interface with radicals and illustrations than in the group using the interface with animations. The recognition rate of the group using the interface along with animations was higher still than the group using the interface with the pinyin and English translations. Therefore, if learners can develop an awareness of the semantic and phonetic components of characters, as a result of incorporating radicals and their derivatives in instruction, better learning performances can be expected.

While the aforementioned research (Jin, 2003) asked participants to memorize Chinese characters, a separate study conducted by Lam, Ki, Chung, and Ko (2000) actually combined computer-assisted language learning and a radical-derived character instruction. In their study, these authors provided Chinese children with the Dragon Wise Series software, which considered 500 Chinese characters. To better motivate children to learn using the radical-derived character learning strategy, topics such as Rhymes, Interactive Exercises on Character Origin, Stroke Sequence, Character Component, Morphological Component, and Chinese Character Knowledge Base were designed. Lam et al. (2001) further invited instructors to use the system and offer their feedback. This study indicated that the radical-derived character learning strategy was feasible. However, the researchers did not systematically organize the Chinese characters and phase instruction by their teachability, nor did they provide sufficient instructional procedures and specific assessment indicators to objectively evaluate the learning outcomes. Additionally, the results could only be generalized to native Chinese children, and the authors did not use this system to investigate whether or not a positive learning outcome could be seen in CFL students using radicals to derive characters. Therefore, it is necessary to further examine the strategy’s feasibility and applicability.

The purpose of this study was to investigate CFL students’ learning outcomes. We chose the radical-derived character teaching method as our instructional approach since their effectiveness has been recognized in previous studies. Along with this, we designed an e-learning platform that provides multimedia learning materials and a user-friendly operational interface. The role of the e-learning platform is to emphasize radical-derived character instruction though computer-assisted language learning. We expected that this combination of content and technique would collectively contribute to productive Chinese language learning.

METHODOLOGY

Design

A nonequivalent pretest-posttest, quasi-experimental design was adopted for this study. The independent variable had two levels and considered the type of instruction experienced in an intensive Language Study Program for Chinese as a Second Language: Chinese language instruction with a radical-derived character teaching method (experimental group) versus traditional Chinese language instruction with word-based teaching strategy (comparison group). The dependent variables were accuracy rates on a Chinese Orthographic Knowledge test, which consisted of a radical recognition test, a semantic radical awareness test, and a phonetic radical awareness test. The participants in both the experimental group and comparison group were pretested immediately before the three-week treatment. The pre-test scores were used as covariates to control for the influence of the number of Chinese characters that students knew before the experiment. During the experimental period, each group received an equivalent amount of instructional time but under different teaching strategies. At the end of the treatment period, all participants were post-tested with identical subtests of the Chinese Orthographic Knowledge test.

Participants

A total of 129 Chinese heritage language learners participated in the study, including 68 females and 61 males, their ages ranging from 19 to 25. One hundred participants had English as their native language, 27 had other alphabetic languages as their native languages (including French = 5, German = 5, Spanish = 5, Thai = 5, Portuguese = 2, Swedish = 2, Arabic = 1, Bahasa Indonesian = 1, and Danish = 1), and two had a logographic language (Japanese, in this case) as their native language (see Table 1 for more demographic data). The majority of learners were from Chinese-American families and either their fathers or their mothers were Chinese native speakers. Note that, from the perspective of literacy development, these students' reading capacities were predicted by the literature to be quite equal to CFL learners due to heavily restricted written language input and experience (Koda, Zhang, & Yang, 2008). Furthermore, their Chinese language proficiency was highly heterogeneous since they had differing amounts of exposure to Chinese language environments. After taking the placement tests developed by the Overseas Compatriot Affairs Commission, all CFL learners were placed among eight classes according to their scores. Students in odd numbered classes (Class 1, Class 3, Class 5, Class 7 and Class 9) were assigned to the experimental group (e-learning radical-derived character instruction); and the remaining learners (Class 2, Class 4, Class 6, Class 8 and Class 10) were assigned to the comparison group (traditional lecturing instruction). Following the placement test, the three-week Chinese learning program was conducted. This program ended with achievement tests, which were also developed by the Overseas Compatriot Affairs Commission.

Table 1. *Demographic Data of Participants*

	Experimental Group (*n* = 69)		Comparison Group (*n* = 60)	
Gender				
Men	36	(47.8%)	25	(58.3%)
Women	33	(52.2%)	35	(41.7%)
Age				
19	19	(27.5%)	11	(18.3%)
20	20	(29.0%)	18	(30.0%)
21	5	(7.2%)	13	(21.7%)
22	10	(14.5%)	8	(13.3%)
23	6	(8.7%)	7	(11.7%)
24	7	(10.1%)	2	(3.3%)
25	2	(2.9%)	1	(1.7%)
Language system				
Alphabetic				
English	54	(78.3%)	46	(76.6%)
Others	14	(20.2%)	13	(20.0%)
Logographic	1	(1.4%)	1	(1.7%)

Instruments

A series of tests created by Hung and Fang (Hung, 2006; Hung & Fang, 2006a, 2006b) was used as a reference when designing our research instrument: the Chinese Orthographic Knowledge Test. This test consists of three constructs of Chinese orthography—radical recognition, semantic radical awareness, and phonetic radical awareness—and was used to assess the participants' understanding of Chinese orthography before and after they received instruction. The researchers modified the original tests because they are designed for native Chinese speaking learners between the third and ninth grades. The researchers believed that the original test content would be too difficult for CSL/CFL students and that it would not assess the variance among the different levels of Chinese language proficiency for this new user group. For this reason, we compiled our own test questions so that the resulting test would more accurately reflect the CFL students' understanding of Chinese orthography.

Each of the three subtests is described below, along with a sample question.

1. Radical recognition test: to understand if our research participants were able to recognize and identify the characters that are associated with the target radicals.

( ) Which character has the radical (symbol) 木 (mu4, wood)?

① 件 (jian4, piece) ② 科 (ke1, subject) ③ 材 (tsai2, material) ④ 料 (liao4, material)

2. Semantic radical awareness test: to evaluate if the participants were able to know where the permissible position of a specific radical is within a character.

( ) Which character is most associated with the meaning of the character 樹 (shu4, tree)?

① 秉 (bing4, grasp) ② 沐 (mu4, take a bath) ③ 悖 (bei4, rebellious) ④ 梢 (shao1, tip)

3. Phonetic radical awareness test: to assess if the participants were able to understand where a specific phonetic radical is within a character.

( ) Which character is pronounced "li3"?

① 種 (zhong3, species) ② 媦 (wei4, sister) ③ 裡 (li3, inside) ④ 野 (ye3, wild)

In this test, there were 22, 13, and 12 items in each of the aforementioned subtests, respectively (see Appendix A for other items). Each item was multiple choice; the participants received 1 point if they chose the correct answer and 0 points otherwise. The participants' overall recognition ability of Chinese orthography was represented not only by their performance on each subtest, but also by the total score from the average of the three subtests. The test performed reliably. The Cronbach's α value for the reliability for each of the above subtests was .947, .881, and .857, respectively, which is higher than the recommended standard of .700 (Nunnally, 1978). Additionally, these subtests exhibited good content validity between the test items and the knowledge being assessed, since all content was examined and revised by senior Chinese teachers and experts.

Chinese Radical-derived Character E-learning Platform

The e-learning material was developed by senior Chinese teachers and digital experts. It was divided into three categories: introduction of radical orthography, radical-derived character instruction, and whole character instruction. Given that participants may have learned either Hanyu Pinyin or BoPoMoFo, the platform was designed so that the participants could learn using the system of phonetic representation that they were familiar with, simply by switching a button.

The learning content of the system is taken from the Chinese Orthography Database (Chen et al., 2011). The database contains the sounds, meaning, radicals, and word frequency of the 6097 most frequently-used traditional Chinese characters, as defined by the Big–5 encoding method (Chinese Foundation for Digitization Technology, 2010) and the Chinese Knowledge and Information Processing group (Academia Sinica, 2010). In total, Chen et al. (2011) consider that there are 439 radicals. They also define

11 configuration categories (i.e., the spatial structure of the radicals): single, vertical, horizontal, total enclosure, left-top-right enclosure, left-bottom-right enclosure, top-left-bottom enclosure, left-top enclosure, right-top enclosure, left-bottom enclosure, and left-right enclosure. With these configurations, a proposition formalism of Chinese character constituents is created. For example, the character 綴 (zhui4, decorate) can be represented as | (糸, | (– (又, 又), – (又, 又))). Among these symbols, "|" represents the horizontal formation relation, and "–" represents the vertical formation relation. Through these configurations and combinations of radicals, the database can be used to calculate the most frequently used orthographic indices (including configuration regularity, structure-position regularity, phonetic consistency, and semantic transparency).

In the introductory section to radical orthography, the database system's contents include structural relations, radical definitions, phonetic radicals, semantic radicals, and radicals with phonetic and semantic functions. In addition to the information on form, sound, and meaning features of Chinese characters, the system also provides clear structural figures (see Figure 1 below) and example characters composed of the radicals, so that the orthographic knowledge is explicitly shown in the material.

戒是「戈」和「廾」右上左下組合而成

勾是「勹」和「人」右上左下組合而成

氣是「气」和「米」右上左下組合而成

金的衍生字

部件「金」能表意的衍生字主要由「左右」的空間關係所構成。

Figure 1. Introduction and example of the right-top enclosure character (left). Example of the radical character 金 (jin1, metal) and its derived characters (right).

In the section describing radical-derived character instruction, the materials were chosen based on the fact that radicals in the database are divided into two categories: the first is radical characters or characters-as-radicals; the other is non-character radicals. Radical characters are radicals that can be used alone as a character, such as 金 (jin1, metal) or 土 (tu3, dirt). Non-character radicals are radicals that cannot be used alone as a character, such as 厂 (han3, cave) or 耂 (lao3, aged). Given that the non-character radicals have less clear phonetic and semantic information, the materials used in this research were limited to radical characters. Additionally, to highlight the function of the radical characters, the radicals were categorized into phonograms and logographs. The logographs fell into seven varieties (e.g., nature, human body, numbers, animals, plants, instruments, and others), and characters were selected based on the radical-derived character instruction principle. The term radical-derived character refers to the idea that, using radical extension, one can derive characters, and these, more or less, encompass the phonetic and semantic information of the radicals. For example, in Figure 2, the characters that are derived from the radical character 金 (jin1, metal) are 錢 (qian2, money), 釘 (ding1, nail), 針 (zhen1, needle), 鈴 (ling2, jingle), 鋒 (feng1, sharp), 銅 (tong2, copper), 銀 (yin2, silver), 銷 (xiao1, metal), 鈔 (chao1, bill), all of which have meanings associated with metal, metal products, or money. Using this radical-derived character learning strategy can simplify learning Chinese characters. Therefore, the derived characters were chosen carefully so that the phonetic and semantic components of the radicals would be explicitly related. The examples and frequency percentages of the selected characters are as follows.

For the radical character instruction of the semantic radicals, 11 radical characters were selected that have the highest token frequency and explicit semantic information in the database. These were divided into the categories of nature (eight semantic radicals: 山 (shan1, mountain), 金 (jin1, metal), 雨 (yu3, rain), 土 (tu3, dirt), 日 (ri4, day), 木 (mu4, wood), 火 (huo3, fire), 穴 (xue4, cave)) and animals (three logographic radicals: 虫 (hui3, worm), 馬 (ma3, horse), 魚 (yu2, fish)). The derived characters included in the study have more than 67% semantic transparency[4] in the database and account for 100% of the logographs in the learning material. In addition, each radical character can be extended to more than eight derived characters, as shown in Appendix B.

As for the phonetic radicals, to emphasize the phonetic components in Chinese and their phonetic function, radical characters were selected that have high consistency in reflecting their characters' sounds (12 phonetic radical characters: 里 (li3, neighborhood), 巴 (ba1, cling to), 文 (wen1, word), 主 (zhu3, host), 巨 (ju4, giant), 正 (zheng4, correct), 昌 (chang1, prosperous), 朱 (zhu1, red or a family name), 交 (jiao1, cross), 侖 (lun2, logical sequence), 其 (qi2, third person pronoun), 章 (zhang1, chapter)). All characters chosen had more than 82% phonetic consistency[5] in the database and accounted for 100% in the learning material. In total, 73 characters were derived from these radical characters and are listed in Appendix C. Overall, the learners were exposed to 233 Chinese characters after learning the phonetic and semantic radical characters and their derived characters in the learning material.

Finally, for the section of whole character instruction demonstrating each character's content and information, the material was divided into three parts: meaning description, stroke practice, and character transformation. Take the example of the radical character 金 (jin1, metal) and its derived character 錢 (qian2, money) (see Figure 2 below). Its meaning description includes how it is pronounced (shown by BoPoMoFo and Hanyu Pinyin), its English translation, its simplified Chinese character, the words that are composed of the character, and the English translations of those words. This enables the learners to construct their knowledge of the character's shape, sound, and meaning step by step. The stroke practice exposes users to computer-animated writing. A 3 by 3 background grid, highlighted animation to show the stroke order, and pause and start buttons provide self-paced learning for users. Finally, the Chinese character transformation not only makes learning more interesting but also enables the learners to observe shape transformations through different fonts such as bronze inscription, small seal script, and clerical script.

注音符號：ㄐㄧㄣ
漢語拼音：jīn
英文解釋：gold
簡體字：金
詞彙：金融,資金,基金
詞彙的英文解釋：finance, fund,a fundation

注音符號：ㄑㄧㄢˊ
漢語拼音：qián
英文解釋：money
簡體字：钱
詞彙：錢包,錢財,賺錢
詞彙的英文解釋：
a wallet, wealth, make money

Figure 2. A page from the whole character instruction section showing on the left the radical character 金 (jin1, metal) and its derived character 錢 (qian2, money).

Taken together, the above sections in the e-learning platform highlighted the virtues of the radical-derived character instructional approach and provided learners with multi-modal inputs to learn Chinese characters. Visually, the colorful combinations of structures and radicals can elicit cognitive engagement on the part of students, which helps them to notice the lexical sub-units of characters. Auditorily, the pronunciations of phonetic radicals and their derived characters can strengthen the students' knowledge about phonetic radicals. As for motivation, the animations showing the writing sequence can draw the students' attention and then reinforce their recognition of the characters, and finally, the character transformation illustration can make the learning process informative and interesting.

Procedure

This experiment lasted for three weeks. Before the formal experiment started, the participants from the experimental group and the comparison group both took the Chinese Orthographic Knowledge test as a pretest. The instructor of each class conducted the pretest before any class instruction commenced. Both groups took the four-hour-a-day classes that trained the learners in Chinese listening comprehension, speaking, reading, and writing. Using the e-learning platform as an auxiliary teaching tool, the experimental group instructors employed it flexibly and chose appropriate radical characters that matched the curricula of their classes. The instruction workflow is shown in Figure 3. First, the instructors introduced radical character knowledge for one hour as initial radical knowledge learning. Each day, the instructors spent approximately half of an hour teaching one or more groups of radical-derived characters. In a daily cycle, a specific radical character was introduced, followed by more than six derived characters. Then, the students were asked to finish an exercise to strengthen and consolidate their knowledge of the group of radical-derived characters. The exercise was composed of 10 multiple choice questions, half of which asked the students to distinguish the form of the learned radical from several orthographically similar radicals, and half of which required students to select a character which conveyed the meaning or sound of the learned radical. Within three weeks, more than 15 radical characters and their derived characters were taught.

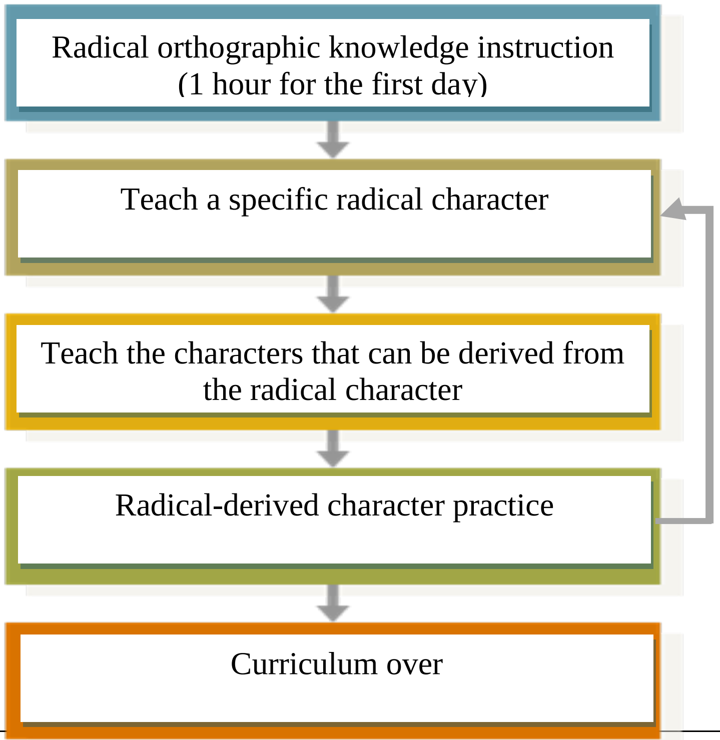

Figure 3. The instruction workflow of the experimental group instructors teaching with the learning platform. The students invested 0.5 hours per day, five days per week, for three weeks, totaling 7.5 hours of contact with this instructional method.

In contrast to the experimental group, the comparison group instructors maintained the traditional word-based instruction. They used curriculum materials identical to the experimental group, while the core of their pedagogical treatment was the collocation of words within a contextual topic. To implement the word-based instructional approach, core activities such as phrase practice, sentence making, and text reading were repeatedly conducted. Instructors would not direct students' attentions to the deconstructed orthographic units of Chinese characters, even though the learning content might include single-character words. Once the vocabulary, lesson, and grammar sections of the lesson were finished, class practice focused on word usage and reading comprehension. If there was any remaining free time, the instructors taught students to write the characters that appeared in the lesson.

After the three-week instruction period, both groups of learners took the posttest. The item types of the posttest were the same as the pretest. All the specific test items were new characters for all students, in order to test the generalization of the radical knowledge of the experiment group and to make the test fair for both groups.

RESULTS

To control for effects caused by the different Chinese proficiency levels, the pretest scores were entered as a covariate in a one-way multivariate analysis of covariance (MANCOVA), with each group being one of two levels of the independent variable, and the three posttest scores as the dependent variables.

Before carrying out the MANCOVA, we conducted an evaluation of assumptions of normality, homogeneity of variance, homogeneity of regression slopes, and homogeneity of covariance matrices. All assumptions were satisfied except for those between the radical recognition posttest and covariate pretest scores. Hence, we removed the radical recognition subtest analysis from the study, leaving only two subtest analyses of the Chinese Orthography Knowledge test.

We used MANCOVA to compare the difference of the means of the two subtests between the experimental group and the comparison group. Significant difference was found: $\Lambda = .879$, $F(2, 124) = 8.51$, $p < .001$. Then we carried out the post-hoc comparisons comparing the subtests of the experimental group to the comparison group. In the test of semantic radical awareness, the adjusted mean of the experimental group (7.33) was significantly higher than that of the comparison group (6.07) ($F(1, 126) = 7.300$, $p = .008$). Also, in the phonetic awareness test, the adjusted mean of the experimental group (8.09) was significantly higher than that of the comparison group (5.93) ($F(1, 123) = 15.073$, $p < .001$).

Table 2. *The mean, standard deviation, and the adjusted mean of the two groups*

		Experimental Group (*n* = 69)			Comparison group (*n* = 60)			*F*
		M	*SD*	Adjusted Mean	*M*	*SD*	Adjusted Mean	
Radical Recognition	pretest	18.68	4.73	20.94	18.42	4.59	19.57	5.292
	posttest	20.86	2.57		19.67	4.46		
Semantic	pretest	6.67	4.06	7.33	7.27	4.16	6.07	7.300*

subtests	Radical Awareness	posttest	7.16	3.06		6.27	2.90		
	Phonetic Radical Awareness	pretest	5.83	3.53	8.09	6.53	3.73	5.93	15.073*
		posttest	7.88	3.75		6.17	3.56		
total	Orthography Knowledge Test	pretest	31.17	9.93	36.12	32.22	10.35	31.84	12.928*
		posttest	35.90	7.59		32.10	8.84		

Note. The scores in the total test and three subtests are 37, 22, 13 and 12, respectively. **p* < .05.

DISCUSSION AND CONCLUSION

This study used the Chinese Orthography Database (Chen et al., 2011) to design learning material for Chinese radical characters. The material included a total of 233 phonetic and semantic radical characters and their derived characters. The research participants were Western heritage Chinese learners who were exposed to three weeks of radical-derived character instruction. Each week participants learned 7 to 8 phonetic or semantic radical characters and their derived characters. Results showed that the experimental group had significantly better performance than the comparison group in radical recognition, semantic radical awareness, and phonetic radical awareness. This supports the view that understanding radicals plays an important role in the process of acquiring Chinese orthographic knowledge.

The results of this experiment confirm the inferences drawn from previous studies that understanding radicals is crucial for learning Chinese characters (Lam et al., 2004; Huang, 2006). What is different from former work is that this study, in addition to validating the possibility of the radical-derived character instruction from a theoretical perspective (Huang, 2008), empirically supports the effectiveness of the radical-derived character instruction. In particular, with the addition of e-learning materials, after receiving the three-week short-term curriculum, CFL learners with different levels of Chinese proficiency could improve their recognition ability in Chinese orthographic knowledge to a level that usually takes beginning learners several months (Liu et al., 2007) or a year (Jackson, Everson, & Ke, 2003) to achieve.

Furthermore, after employing the e-learning platform to learn Chinese characters, the experimental group had significant improvements in not only semantic radical tests but also phonetic radical awareness tests. This suggests that the experimental group not only understands that the radical characters can imply both the meaning and pronunciation, but that they can also distinguish the different radicals when embedded in Chinese characters, even though this group learned many radical characters and their derivative characters in three weeks. Such a research result extends the population of CFL learners in the study of the digital Chinese character instruction (Lam et al., 2004). Both studies suggest that the radical-derived character learning strategy helps inform Chinese orthographic knowledge. The study of Lam et al. only included learners whose first language was Chinese, and its purpose was to investigate how children’s character recognition processes were influenced by the assistance of digital materials. Our study had CFL students as participants and demonstrates the effectiveness of incorporating digital learning materials in facilitating radical-derived character instruction in this population. In short, whether it is Chinese-as-first-language students or CFL students in the process of learning Chinese characters, digital radical-derived character instruction seems to improve learners’ recognition ability of Chinese orthography.

On the other hand, in previous studies, CFL students at the early stages of learning never had practiced the strategy of simultaneously using both the phonetic and semantic components of characters. Instead, they learned the individual phonetic or semantic components separately. This study demonstrates that as long as the explicit instruction of Chinese orthographic knowledge is systematically conducted, learners can still improve their recognition ability of Chinese orthography even if they learn the semantic and phonetic functions of the radicals at the same time. They will not confuse these different radical types with each other, and can they will perform better on semantic and phonetic radical awareness tasks. Therefore, we suggest that learners' cognitive load (e.g., learning Chinese orthography through summarizing) can be reduced through teachers' proper use of this e-learning platform. For instance, the instructors can train the CFL students to consciously learn what implications the phonetic and semantic radicals have in the Chinese characters. With such implications in mind, students can better understand character composition. Thus, learners can develop Chinese orthographic awareness earlier, complete the process from non-automation to automation, and show some improvements in learning Chinese characters.

In terms of this study's implications, although the instructional content of this study focused on traditional Chinese, we believe that the results will also generalize to studies associated with simplified Chinese learning, given that traditional and simplified Chinese are both logographic writing forms. Additionally, studies such as those by Shen (2005) or Zhao and Jiang (2002) have been conducted in simplified Chinese learning fields and these suggested that the radical-derived character learning strategy is an efficient Chinese character learning method. Our study, using a nonequivalent pretest-posttest, quasi-experiment design, demonstrated that radical-based strategy is also valid in traditional Chinese character learning, providing a convergent view from previous quantitative studies. In the mean time, researchers should bear in mind that there are differences between Chinese-as-first-language learners and CFL students in their respective processes of learning Chinese characters. The latter know far fewer Chinese characters, have lower levels of Chinese proficiency, and have less Chinese cultural knowledge than the former. These factors may constrain CFL learners' understanding of the functions of phonetic and semantic radicals. Our research suggests that instructors should conduct gradual instruction of the radicals' characteristics and develop their students' ability to recognize and analyze radicals. For example, instructors can bring together the characters from Hanyu Shuiping Kaoshi (HSK, 8822 words), Test of Chinese as a Foreign Language (TOCFL, 8000 words), and the Chinese characters issued by the Ministry of Education in France for the first-stage learning materials for the Chinese language learning beginners and identify both the radicals and their derivative characters in these materials. Also, to avoid negative transfer and overgeneralization on the part of learners, instructors need to take advantage of the comprehensive database of the radicals and whole characters to sort out characters that are most worthy of instruction from those that may be confusing from the perspective of shape or sounds. Doing this will help learners identify useful patterns when recognizing or learning Chinese characters.

Finally, given that e-learning tools have the possibility of diversifying learning materials, promoting self-paced learning, and increasing accessibility without time and space limitations (Gao, 2006), the significant results of our research can be attributed to the radical-derived character e-learning platform. In the radical recognition test, compared to the comparison group, the experimental group had better knowledge of radicals and the stroke orders of the whole characters. For example, they could tell the difference between 木 (mu4, wood) and 禾 (he2, standing grain). This can be attributed to the fact that the e-learning materials employ animation to demonstrate the character transformation of the radicals and the stroke orders. Therefore, our research emphasizes the effectiveness of incorporating digitalization to learn Chinese characters. This radical-derived character e-learning system can not only work as an in-class teaching aid for CFL students, but also breaks the limitation of time and space, enabling learners to study Chinese radicals and their derived characters by themselves at home, providing accessibility, and increasing learning motivation. Additionally, this system incorporates a bottom-up and data-driven database. It offers the ability to sort out the representative phonetic and semantic radical characters with moderate difficulty and use them as the e-learning materials, so that the contents of the system are easily amenable to future scientific exploration. With this e-learning system, learners can absorb the relevant Chinese orthographic knowledge with their own appropriate learning strategies and organize the explicit orthographic knowledge with more efficiency with user-friendly interface customization.

In sum, the digital radical-derived character teaching strategy used in this research is different from the traditional Chinese language instruction with word-based instructional method. Such a strategy has more interesting and efficient ways to encourage active learning. The systematic learning strategies help learners to better control the contents and principles of Chinese radical characters, accelerating the learning of more Chinese characters.

In the future, this radical-derived character e-learning system will be supplemented with practice exercises for words, sentences, and articles, and will also have online tests. In this way, the learners can have immediate feedback once they have studied the whole series of radicals and the information about their derived characters. This can further solidify and strengthen the new knowledge they acquire. In addition, the e-learning system will incorporate learning strategies such as memorization techniques and story-telling to enrich the instructional contents, so that Chinese character learning performance can be boosted and the digital contents and topics of Chinese character learning can be more profound.

APPENDIX A. Orthography knowledge test (BoPoMoFo version, selected items)

Part 1. Radical recognition test (22 items in total)

1. (　　) 下面哪一個字有「木」的部件（符號）？

Which word has the “木” radical?

① 件　② 科　③ 材　④ 料

2. (　　) 下面哪一個字有「火」的部件（符號）？

Which word has the “火” radical?

① 樂　② 榮　③ 舜　④ 華

Part 2. Semantic radical awareness test (13 items in total)

1. (　　) 下面哪一個字與「樹」的意思最有關係？

Which word is related with “tree”?

① 秉　② 沐　③ 悖　④ 梢

2. (　　) 下面哪一個字與「熱、亮」的意思最有關係？

Which word is related with “heat” or “light”?

① 袖　② 烘　③ 錄　④ 伙

Part 3. Phonetic radical awareness test (12 items in total)

1. (　　) 下面哪一個字是發「ㄨㄣˊ」的音？
Which word is pronounced “wen2” ?
① 便　② 叛　③ 蚊　④ 攻

2. (　　) 下面哪一個字是發「ㄅㄚˇ」的音？
Which word is pronounced “ba3” ?
① 拍　② 把　③ 玘　④ 琶

APPENDIX B. Categories, radical characters, and the derived characters of the semantic radical-derived character instruction

Category	Radical Character	Derived Characters	Category	Radical Character	Derived Characters
Nature	山	屹 峽 峰 峻 崗 岸 崇 崩 岔 島	Nature	火	炒 炮 烤 熄 熔 煙 炎 榮 災 炭
Nature	金	錢 釘 針 鈴 鋒 銅 銀 銷 鈔	Nature	穴	窗 突 穿 挖 究 竅 腔 窄 窩 空
Nature	雨	雲 雷 電 雪 霜 零 震 霉 霖	Animal	虫	蚊 蚯 蛀 蝌 蚪 蚓 蝶 蜂 蛾
Nature	土	地 坦 埋 境 坑 城 堆 址 坡 場 塑 壁 塵 壘	Animal	馬	馳 駐 騙 駛 騎 騷 駕 驚
Nature	日	明 晚 晒 昨 晴 時 映 昇 旦 早 旱 昏 春 昔	Animal	魚	鮮 魷 鮭 鯛 鯨 鯉 鱗 鰻 鮪 鯊
Nature	木	林 材 框 植 杯 根 柱 枝 板 樹 椅 休 棵 床 茶 架 桌 集 朵 李			

APPENDIX C. Categories, radical characters, and the derived characters of the phonetic radical-derived character instruction

Radical Character	Derived Character	Radical Character	Derived Character
里	俚 哩 娌 浬 理 裡 貍 鋰 鯉	昌	倡 唱 娼 猖 鯧
巴	爸 疤 笆 芭 把 吧 靶	朱	侏 株 珠 硃 蛛 誅 銖
文	蚊 紋 抆 玟 汶 紊 雯	交	姣 狡 皎 絞 蛟 跤 較 鉸 餃 鮫 佼 珓
主	注 蛀 註 駐 住 拄 柱 炷	侖	倫 掄 淪 綸 論 輪
巨	拒 炬 距 鉅 矩 詎	其	淇 棋 琪 騏 祺 旗 麒 蜞
正	征 怔 証 鉦	章	樟 璋 漳 蟑 獐 障 幛 嶂

NOTES

1. This issue is usually encountered by students who learn Chinese as a second language (CSL) in a country where Chinese is the official language, students who study Chinese as a foreign language (CFL) in a non-Chinese-speaking region, or students who acquire Chinese as a heritage language (CHL) since their immigrated family continues to speak Chinese at home. Though the backgrounds of these students are idiosyncratic, learning Chinese is their common goal. In this article, the term CFL is used to cover all above usages (i.e., CSL, CFL, and CHL) since it conveys broad meaning and implications in second language acquisition research (Kroll & de Groot, 2005).

2. From this first set of examples, "里 neighborhood, li3" indicates the form, meaning, and sound of the character, 里. Here, the character is 里, which means neighborhood; "li3" is the character's pronunciation written using Hanyu-Pinyin system, a phonetic transcription for Mandarin Chinese. The letters represent the initial and final of the sound-syllable, while the digit at the end represents one of four tones in Mandarin Chinese.

3. Hanyu-Pinyin and BoPoMoFo (also known as "Zhuyinfuhao") are two commonly used phonetic transcription systems for Mandarin Chinese. The former is the official standard in Mainland China (Chinese characters are transliterated into 26 Latin alphabet letters), and the latter is the official standard in Taiwan (consisting of 37 phonetic symbols and four tone markers). Both of the systems use a sequence of their phonetic symbols to transcribe every Mandarin syllable sound.

4. Semantic transparency means the proportion presented by direct or indirect relationship in meaning between a component character and its character derivations. For example, "魚 (fish, yu2)", as a semantic component character, has 36 derived characters: **漁 魯 嚕 櫓 魷 穌 蘇 囌 鮑 薊 鮪 鮫 鮭 鮮 蘚 癬 鯀 鯈 鯉 鯊 鯽 鯖 鯛 鯧 鯨 鰍 鰭 鰱 鰻 鰾 鱉 鱟 鱔 鱖 鱷 鱸**. Among these character derivations, there are 27 characters whose semantic radical is 魚. Thus, the semantic transparency of 魚 is calculated as 27/36 x 100% = 75%.

5. Phonetic consistency means the proportion calculated by the similarity of homophones between a component character and its character derivations, without the consideration of four tones. For instance, the phonological character "里 (neighbor, li3)" has 17 character derivations: **俚 哩 埋 娌 浬 狸 理 野 童 量 裡 貍 霾 釐 纏 鋰 鯉**. Among these 17 characters, there are 11 characters, **俚 哩 娌 浬 狸 理 裡 貍 釐 鋰 鯉**, which have the same pronunciation with character 里. Therefore, the phonetic consistency of 里 is calculated as 11/17 x 100% = 65%.

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REFERENCES

Big-5 encoding method (2010, January, 1). Taipei: Chinese Foundation for Digitization Technology. Retrieved from: http://www.cmex.org.tw/info009.htm

Bush, M., & Terry, R. (1997). *Technology-Enhanced Language Learning.* Lincolnwood, IL: National Textbook Co.

Chen, H. C., Chang, L. Y., Chou, Y. S., Sung, Y. T., & Chang, K. E. (2011). Construction of Chinese Orthographic Database for Chinese Character Instruction. *Bulletin of Educational Psychology, 43* (Special Issue on Reading), 269–290.

Clark, J.M., & Paivio, A. (1991). Dual coding theory and education. *Educational Media*, *24* (4), 333–339.

Chen, H.Y., & Liu, K.Y. (2008). Web-based synchronized multimedia lecture system design for teaching learning Chinese as second language. *Computers & Education*, *50*, 693–702.

Chinese Knowledge and Information Processing group (2010, January, 1). Taipei, TW: Academia Sinica. Retrieved from: http://ckip.iis.sinica.edu.tw/CKIP/engversion/index.htm

Cobb, T. (2007). Computing the vocabulary demands of L2 reading. *Language Learning & Technology, 11*(3), 38–63. Retrieved from http://llt.msu.edu/vol11num3/pdf/cobb.pdf

Cook, V. (2003). Introduction: The changing LI in the L2 user's mind. In V. Cook (Ed.), *Effects of the second language on the first* (pp. 1–18). Clevedon, UK: Multilingual Matters.

Dulay, H., Burt, M., & Krashen, S. (1982). *Language two.* New York, NY: Oxford University Press.

Fan, L. N. (2003). The strategy research of teaching Chinese as a second language. *Journal of National University of Tainan*, *37* (2), 1–16.

Gao, Y. J. (2006). E-learning—New Trend for Learning. *E-Soc Journal*. *57*, Retrieved from http://www.nhu.edu.tw/~society/e-j/57/57-22.htm

Gobert, F., Lane, P. C. R., Croker, S., Cheng, P. C-H., Jones, G., Oliver, I. & Pine, J. M. (2001). Chunking mechanisms in human learning. *TRENDS in Cognitive Sciences*, *5*, 236-243.

Ho, C.S.H., & Bryant, P. (1997). Phonological skills are important in learning to read Chinese. *Developmental Psychology*, *33*, 946–951.

Huang, P. J. (2006). *Theory and practice of Chinese character instruction.* Taipei, TW: Lexis Book Co.

Huang, Y. P. (2008). Investigation on the effectiveness of radical instruction in character recognition instruction and its application. *The Elementary Education Journal*. *55* (1), 63–67.

Huang, H.-S., & Hanley, J. R. (1994). Phonological awareness and visual skills in learning to read Chinese and English. *Cognition*, *54*, 73–98.

Hung, L. Y. (2006). *Test on Radical Recognition*. Taipei, TW: Special Education Unit, Ministry of Education.

Hung, L. Y. & Fang, J. Y. (2006a). *Test on Semantic Radicals*. Taipei, TW: Special Education Unit, Ministry of Education.

Hung, L. Y. & Fang, J. Y. (2006b). *Test on Phonetic Radicals*. Taipei, TW: Special Education Unit, Ministry of Education.

Larsen-Freeman, D., & Long, M. (1991). *An introduction to second language acquisition research*. London: Longman.

Jackson, N. E., Everson, M. E., & Ke, C. (2003). Beginning readers' awareness of the orthographic structure of semantic-phonetic compounds: Lessons from a study of learners of Chinese as a foreign language. In C. McBride-Chang & H.-C. Chen (Eds.), *Reading development in Chinese children* (pp. 141–153). London, UK: Praeger.

Jiang, X. (2008). *Research on Words of Teaching Chinese as a Second Language and Learning to Read*. Beijing, CN: Beijing Language and Culture University Press.

Jiang, W., & Ramsay, G. (2005). Rapport-Building CALL in teaching Chinese as a foreign language: an exploratory study. *Language Learning & Technology*, *9*(2), 47–63. Retrieved from http://llt.msu.edu/vol9num2/jiang/default.html

Jin, H. G. (2003). Empirical evidence on character recognition in multimedia Chinese tasks. *Concentric: Studies in English Literature and Linguistics*, *29*(2), 36–58.

Jin, H. G. (2007). Multimedia Effects and Chinese Character Processing: An Empirical Study of CFL Learners from Three Different Orthographic Backgrounds, *Journal for Chinese Language Teachers Association (JCLTA)*, *42*(1), 27–48.

Koda, K., Zhang, Y., & Yang, C. L. (2008). Literacy development in Chinese as a heritage language. In A. W. He, & Y. Xiao (Eds.), *Chinese as a heritage language: Fostering rooted world citizenry* (pp. 137–149). Honolulu, HI: University of Hawaii, National Foreign Language Resources Center.

Kroll, J. F., & de Groot, A. M. B. (Eds.) (2005). *Handbook of bilingualism: Psycholinguistic approaches*. New York, NY: Oxford University Press.

Lam, H. C., Ki, W. W., Chung, A. L. S., & Ko, P. Y. (2000). Experience in Designing Databases for Learning Chinese Characters. *International Journal of Computer Processing of Oriental Languages*, *13*(4), 351.

Lam, H. C., Ki, W. W., Law, N., Chung, A. L. S., Ko, P. Y., Ho, A. H. S., et al. (2001). Designing CALL for learning Chinese characters. *Journal of Computer Assisted Learning*, *17*(1), 115–128. doi: 10.1046/j.1365-2729.2001.00164.x

Lam, H. C., Ki, W. W., Chung, A. L. S., Ko, P. Y., Lai, A. C. Y., Lai, S. M. S., et al. (2004). Original article: Designing learning objects that afford learners the experience of important variations in Chinese characters. *Journal of Computer Assisted Learning*, *20*(2), 114–123. doi: 10.1111/j.1365-2729.2004.00071.x

Lin, C., Huang, C., & Chiang, Y. (2009). Learners' Perspectives on Incorporating Drupal and Web 2.0 Tools in a Blended-learning Chinese Classroom. In G. Siemens & C. Fulford (Eds.), *Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications 2009* (pp. 4223–4228). Chesapeake, VA: AACE.

Lin, M. C., & Wang, P. Y. (2008). A knowledge management system for Chinese language arts teachers. *British Journal of Educational Technology*, *39*(5), 953–943.

Liu, Y., Wang, M., & Perfetti, C.A. (2007). Threshold-style processing of Chinese characters for adult second-language learners. *Memory & Cognition*, *35*(3), 471–480.

Lu, M., Wu, C., Martin, E., & Shah, R. (2009). The Effects of Computer-Assisted Language Learning

(CALL) in Grammar Classrooms. In G. Siemens & C. Fulford (Eds.), *Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications 2009* (pp. 2217–2236). Chesapeake, VA: AACE.

Lu, M. C. (2000). The effectiveness of Chinese stem-deriving instruction on elementary students with severely word-recognition difficulties. *Bulletin of Special Education, 18,* 207–235.

Mayer, R.E., & Moreno, R. (2002). Animation as an aid to multimedia learning. *Educational Psychological Review*, *14* (1), 87–99.

Nunnally, J. C. (1978). Psychometric theory (2nd ed.). New York, NY: McGraw-Hill.

Shen, H. H. (2000). Radical knowledge and character learning among learners of Chinese as a foreign language, *Linguistic Studies*, June, 85–93.

Shen, H. H. (2005). An Investigation of Chinese-Character Learning Strategies among Non-Native Speakers of Chinese. *System: An International Journal of Educational Technology and Applied Linguistics*, *33*(1), 49–68.

Shen, H. H., & Ke, C. (2007). Radical awareness and word acquisition among non-native learners of Chinese. *Modern Language Journal*, *91*(1), 97–111.

Shi, D. G. & Wan, Y. X. (1998). Report on Teaching Chinese as a Second Language. *Research and Language Instruction*, *1*, 37–48.

Shu, H. & Zeng, H. M. (1996). Kids' Awareness and Development of the Phonetic Clues in Chinese Character Structure. *Bulletin of Psychology*. *2*, 160–165

Taft, M., & Chung, K. (1999). Using radicals in teaching Chinese characters to second language learners. *Psychologia*, *42*, 243–251.

Taylor I. & Taylor M.M. (1990) *Psycholinguistics: Learning and Using Language*. Englewood Cliffs, NJ: Prentice-Hall.

Tsai, C. H., Kuo, C. H., Horng, W. B., & Chen, C. W. (2012). Effects on learning logographic character formation in computer-assisted handwriting instruction. *Language Learning & Technology*, *16*(1), 110–130. Retrieved from http://llt.msu.edu/issues/february2012/tsaietal.pdf

Wang, M., Perfetti, C., & Liu, Y. (2003). Alphabetic readers quickly acquire orthographic structure in learning to read Chinese. *Scientific Studies of Reading*, *7*, 183–208.

Wen, C. Y. (2003). Computer-assisted Chinese-character primitives instructional program on word recognition for students with reading disabilities. Unpublished Master Thesis, National Chiayi University of Special Education, Chiayi.

Yeh, S. L. (2000). Structure detection of Chinese characters: Visual search slope as an index of similarity between different-structured characters. *Chinese Journal of Psychology, 42*, 191–126.

Yeh, S. L., Li, J. L., & Chen, K. M. (1999). Classification of the shapes of Chinese characters: Verification by different predesignated categories and varied sample sizes. *Chinese Journal of Psychology, 41*, 65–85.

Zhao, G. & Jiang, X. (2002). What is the Most Effective Strategy for Learning Chinese Characters: A Survey Among CSL Beginners. *Applied Linguistics*, *2*, 79–85.

Zheng, Y. B. (2010). A Study on Furthering Internationalization of Chinese. *Journal of Xihua University (Philosophy & Social Sciences)*, *29*(6), 67–70.