Chinese Radicals in Spaced Repetition Systems: a pilot study on the acquisition of Chinese characters by students learning Chinese as a foreign language

Jeremiah Daneil de la Rouviere

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Supervisor: E.K. Bergman

Faculty of Arts and Social Sciences

Department of Modern Foreign Languages

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Abstract

This thesis explores the effect on learning Chinese characters for learners of Chinese as foreign language through implementing the unique properties of the Chinese script in a prototype spaced repetition system. Both Chinese radicals and the spacing effect have the potential to positively influence the recall ability of students in learning Chinese characters, however the interaction between the spacing effect and Chinese radicals in spaced repetition system, such as *Anki* and *Mnemosyne*, had not been tested. An experimental spaced repetition system prototype was designed and developed to investigate these interactions. Two groups of students learning Chinese as a foreign language at the University of Stellenbosch studied the same list of Chinese characters in which there were both massed and spaced characters present. One group had additional information on Chinese radicals on the flashcard. The students were given an immediate post-test to test their recall of the meaning and pronunciation of the Chinese characters. The results showed a positive trend for the spacing effect in which students had higher scores for spaced characters, but the recall ability between the two groups of students did not change regardless of whether there was information on Chinese radicals or not. The results were surprising considering the potential positive impact of Chinese radicals on recall. The thesis concludes that the presentation of information on Chinese radicals in a spaced repetition system does not necessarily improve the recall ability of the students. The impact of explicit instruction on the role of Chinese radicals in Chinese characters and the ability of the student to apply this knowledge should be considered for future research.

Opsomming

Die huidige tesis ondersoek die leer van Chinese karakters deur leerders van Chinees as ‘n vreemde taal deur die unieke eienskappe van die Chinese skrif in ‘n prototipe gespasieërde herhalings sisteem te implementeer. Beide Chinese radikale en die spasiërings effek kan potensieël 'n positiewe invloed hê in die vermoë van studente om Chinese karakters te onthou, maar die interaksie tussen die spasiërings effek en Chinese radikale in gespasieërde herhalings sisteme, soos *Anki* en *Mnemosyne*, was tot dusver onbekend. ‘n Eksperimentele gespasieërde herhalings sisteem prototipe was geskep om hierdie interaksie te ondersoek. Twee groepe studente van Chinees as vreemde taal by die Universiteit van Stellenbosch het dieselfde lys karakters gestudeer, waaronder gespasieërde en nie-gespasieërde karakters tuis was. Die twee groepe het verskil deurdat een groep ekstra informasie oor Chinese radikale gehad het op die voorkant van 'n flitskaart. Die studente het dadelik daarna ‘n toets ontvang waar hul die betekenis en uitspraak van die Chinese karakters moes onthou. Die resultate het ‘n positiewe neiging getoon vir die spasiërings effek waar studente hoër punte ontvang het vir gespasieërde karakters, maar die vermoë om die karakters te onthou het nie verskil tussen die twee groepe nie. Die resultate was ‘n verassing juis omdat daar ‘n potensieël positiewe invloed kan onstaan deur die impak van Chinese radikale. Die tesis het gevind dat slegs om informasie oor Chinese radikale te wys in ‘n gespasieërde herhalings sisteem nie noodwendig die vermoë van die student om Chinese karakters te onthou verbeter nie. Die impak van eksplisiete instruksie oor die rol wat Chinese radikale in Chinese karakters speel en die vermoë van die student om hierdie kennis toe te pas hoort verder ondersoek te word.

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Chapter 1: Introduction

1.1 Research Rationale

The emergence of China as a considerable force in world economy has made learning Chinese imperative for Westerners for whom this is a daunting task, mainly because of the unfamiliarity of the Chinese script and the number of characters in the language.

My own frustration in trying to master the sheer number of Chinese characters led me to explore alternative avenues and methods in an attempt to improve my effectiveness in learning Chinese characters. One such alternative avenue was an investigation of digital tools in which I came across the concept of spaced repetition systems. These are flashcard-like applications that organize flashcards in a specific way in order to improve the retention of information, and they are often used for learning foreign language vocabulary.

I used spaced repetition systems more often to learn Chinese characters and Chinese vocabulary, but found that the existing applications, such as *Anki* and *Mnemosyne* were inadequate for my purpose. The problem is that while these spaced repetition systems are useful, they were not specifically created for learning Chinese. The reason that this is a concern is that the Chinese script is very different from Western alphabet-based script and that the presentation of the unique properties inherent in the language is not made apparent on the flashcards. To explain: The Chinese script is a logographic script, which means that unlike most Western languages, the grapheme is a morpheme and not a phonetic unit as in alphabetic scripts such as English. Each grapheme in Chinese is a character which has meaning and sound attached to it. Of the more than 30 000 characters in Chinese, each character is made up of components called radicals which are present in every Chinese character. For instance, the Chinese character 洋, means “ocean”, is pronounced as /yáng/ and is constructed out of two radicals: 氵 and 羊. 氵 is the radical for water and 羊 means goat, but 羊 does not contribute meaning to the character, but instead to its pronunciation which is /yáng/. This example serves to clarify that the

radical on the left contributes to the meaning of the character, "water" is related to "ocean", and the radical on the right determines the pronunciation of the character.

Another character, in which one of the radicals is the same as in the previous example, is 痒, which means "to itch" and is pronounced /yǎng/. This character is composed out of the two radicals: 疒 and 羊. The radical on the left means "sickness", and the radical on the right is the same /yáng/ found in 洋. Notice that the tones of the pronunciation of the radical 羊 and pronunciation of the character 痒 are different: /yáng/ and /yǎng/ respectively. The 疒 radical contributes some meaning to the character, in that "sickness" can be related in some way to an itch, but one the meaning of the radical 氵 (water) is clearly more closely related to the meaning of the character 洋 (ocean). This concept of semantic transparency is discussed in more detail in Section 2.1.1.1, but is mentioned here to highlight the possibilities in utilizing these components for more efficient and effective learning of Chinese characters.

Character	Meaning	Pronunciation	Left Radical	Right Radical
洋	Ocean	/yáng/	氵 (water)	羊 (/yáng/)
痒	To itch	/yǎng/	疒 (sickness)	羊 (/yáng/)

By incorporating these unique properties of Chinese orthography into spaced repetition systems a beneficial interaction between these two fields could be found which could improve learning of Chinese characters.

A review of the academic literature shows that radicals play a role in the ability of learners to recall Chinese characters (Dunlap *et al.*, in press; Taft & Chung, 2009). Radicals are processed on a sub-lexical level and are core elements in processing Chinese characters (Taft & Zhu, 2007). Investigation into spaced repetition systems revealed that they use cognitive phenomena such as the spacing effect, the testing effect and the

forgetting curve to improve recall. The spacing effect was the most intriguing and is the cornerstone of spaced repetition systems. In explanation, the further you space repetitions of information apart, the better the brain is able to remember that information. The opposite of spaced repetition is massed presentation, where repetitions of information are presented in immediate succession. The forgetting curve is a manifestation of how far one can push the spacing effect as this is a computation of the optimal spacing of repetitions of information to just before the learner is about to forget the information. Spaced repetition systems use complex algorithms that space these repetitions based on student feedback related to the recall ability of the information on a specific flashcard.

Flashcards and, by association, spaced repetition systems complement a language learner's study of the target language, but one has to ask where this type of learning fits into other areas of foreign language learning? Nation (2007:1) proposed four strands of language learning: meaning-focused input, meaning-focused output, fluency development and language-focused learning. The latter strand refers to learning in which language items, such as grammar and vocabulary are learned deliberately. A balanced approach to foreign language learning should include deliberate learning of vocabulary (Nation, 2007). A lot of research has been done on the spacing effect as well as on the effects of radicals in Chinese orthography, but at the intersection of these areas of research little information is available.

1.2 Research Question

The initial literature review confirmed that awareness of the properties of Chinese orthography and spaced repetition systems, which utilize the spacing effect have a positive effect in learning vocabulary and Chinese characters. There seemed to be potential for the implementation of a unique spaced repetition system designed specifically to exploit the explanatory properties of Chinese script. The question that this thesis thus aims to answer is:

Would a spaced repetition system that incorporates information on Chinese radicals improve the ability of learners of Chinese as a foreign language to recall Chinese characters?

1.3 Research Design and Methodology

An in-depth literature review was done to determine how to construct the experimental digital application. Topics that were reviewed are Chinese orthography; Chinese radicals and their impact on both recall and the ability to read Chinese characters; models and frameworks for cognitive processing of Chinese characters; the role of vocabulary in language learning, specifically in deliberate learning such as the use of flashcards; and the spacing effect and its causes. Finally a review was done of existing studies that could shed light on the research question.

The ADDIE (analysis, design, development, implementation, evaluation) research methodology was followed in order to create and guide development of the experiment to gain further insight into the best way to answer the research question. Although traditional spaced repetition programs, such as *Anki* and *Mnemosyne*, usually space flashcards over longer expanding intervals, this thesis will use shorter equal spaced repetitions to increase turnover time in data gathering for the experiment. Thus, the initial emphasis will be placed on adapting and designing the application in order to make constructive use of the spacing effect.

The experimental application will then be compared to a traditional flashcard application by using a control group. The units of measurement will be determined with further study, but will be set out in terms of the hypothesis and research question.

The structure of the thesis is as follows:

Chapter Two: Literature review
A literature review on the topics proposed in the first paragraph of this section.

Chapter Three: Developing Spaced Repetition Systems
The first three stages of the ADDIE methodology is documented: analysis, design and

development. This is to provide information on existing spaced repetition systems and how the control version of the application was designed and developed.

Chapter Four: Implementation and Evaluation
Here the last two steps of the ADDIE methodology is documented. This focuses on the adjustments made to construct the specific implementation for the experimental version. An analysis of Chinese characters to find the appropriate characters for the experiment is given in this chapter. The hypothesis and procedure for the experiment is stated and then the results of the experiment are discussed.

Chapter Five: Conclusion
Here a summary of the thesis is given as well as a critical review of the research question. Implications of the results of this research study for learning Chinese as foreign language are discussed and recommendations for future research are given.

Chapter 2: Literature Review

This chapter looks at current research on Chinese orthography, the use of Chinese radicals in character recognition and reading development, Chinese lexical models and the role of deliberate learning of vocabulary in foreign language learning. Furthermore, the spacing effect and testing effect are described as these form the basis for flashcard spaced repetition systems. Commercially used computer applications and studies on spaced repetition systems are also described.

2.1 The Chinese Language

Chinese is an umbrella term for a number of dialects spoken in China. Thus, it could refer to Yue, Wu and Mandarin varieties among other dialects in the country. For this thesis, Chinese will refer to Mandarin Chinese, the language spoken by more than 1.2 billion people and which is the official language of the People's Republic of China and Taiwan as well as one of the four official languages of Singapore. Chinese as a written language is unique, as it uses a logographic script and is the only widely used language at present that uses such a script. A logographic script is defined as a script in which the grapheme, which is the smallest meaningful unit in written language, represents a morpheme or word. This is in contrast to an alphabetic script, such as English, where the grapheme represents a phoneme.

	Grapheme	Representation
English	Letter – B	Only phoneme - /b/
Chinese	Morpheme – 河	Pronunciation: /hé/ Meaning: River

Along with having a logographic script, Chinese also has other features not familiar to Westerners, such as having an isolating morphological structure, tonal distinctions on the syllable level, a homophonic phonetic set and a regular word compounding structure of which two syllables is the common size for a word in Chinese.

2.1.1 The Chinese Character

A Chinese character represents one syllable in pronunciation and often has several meanings associated with it. For example, the character 和 is pronounced as /hé/ in Pinyin, and has the following meanings: "gentle", "mild", "harmonious", "on friendly terms", "peace" as well as being used as a conjunction between nouns. However, the pronunciation /hé/ is also related to many other characters: 何, 合, 核, 河, 荷, 盒, 禾, 曷 among others with exactly the same pronunciation, but with different meanings. Those characters have the pronunciation /he/ with a rising tone and do not take other tones into account. This makes the Chinese language homophonic in character.

Moreover, information on the level of the whole character relating to the phonetic and semantic information is often arbitrary. A logographic script, like Chinese, is classified as having a deep orthography. This means that the connection between the grapheme and phoneme is not closely related. There are more than 30, 000 characters in the Chinese language and one needs to know at least 3000 unique characters to be able to read a Chinese newspaper. However, most Chinese vocabulary items consist of a combination of two characters, thus knowing only characters is not enough to read Chinese.

The vast number of Chinese characters a learner of Chinese as foreign language needs to memorize can become a big stumbling block in reading the Chinese script. Chinese characters are not all separate graphemes each with their own semantic and phonetic information, but are constructed of components called radicals of which most are also considered as characters. These radicals form the foundation of every Chinese character. Most characters contain a semantic radical which denotes the meaning of the character and a phonetic radical which denotes the pronunciation of the character. As an example: the character 河 consists of the semantic radical "氵" and the phonetic radical "可". The semantic radical means "water" and aids in deriving the meaning of the character 河 as

"river". The phonetic radical is pronounced as /kě/, which partially aids the pronunciation of 河 as /hé/.

Word - 海洋

Characters – **海** + **洋**

Radicals – 氵, **每** + 氵, 羊

Figure 1: Structure of Chinese Orthography. The final level below radicals are the actual strokes of which there are 8 basic and 29 complex strokes.

Because of the compounding nature of a Chinese character in which the semantic radical is usually on the left and the phonetic radical on the right, De Francis (1989) argues that Chinese characters are not in fact logographic, but rather morphosyllabic, in that

1. Chinese characters represent one syllable, but also one morpheme and,
2. most Chinese characters are composed of two radicals that contain semantic and phonetic information.

A character can, therefore, be described as a semantic-phonetic compound. These compound characters form the majority of Chinese characters at an estimation of 81% (Chen, Allport & Marshall, 1996). Pictographs, indicatives and ideographs are also present in the Chinese script (Williams & Bever, 2010). Pictographs are similar to Egyptian hieroglyphs, in that they resemble pictures, for instance the character 田 which means "field" or 山 which means "mountain". Ideograms are characters which represent abstract ideas through graphical approximation, for example such as the numbers one, two and three, which are written as 一, 二, 三 respectively. Lastly, indicatives are compound ideographs, for example the character 男 which means "man", which is composed out of the characters, 田, meaning "field", and 力, meaning "strength", perhaps a philosophical representation of the idea that man is created from the dust of the field.

In semantic-phonetic compounds, the semantic and phonetic radicals have different variables that respectively predict the semantic and phonetic information on the character level. The five main variables are frequency, combinality, regularity, consistency and transparency, all of which will be discussed in more depth for each type of radical: semantic and phonetic. It is important to document these features, because they influence the recognition of the character. If a study is to be done on recall of Chinese vocabulary, the influences inherent in processing Chinese characters need to be understood in order to control the variables that influence recall and recognition. The semantic and phonetic radical both have different effects on how semantic-phonetic compounds are read. It is thus paramount to understand these effects before conducting a research study that focuses on recall of Chinese characters.

Hsiao and Shillcock (2006) analysed the 3027 most frequent semantic-phonetic compounds found in Chinese. More than 72% of semantic-phonetic compounds have a left-right radical structure: left, semantic; right, phonetic. Other structures that occur are top-down; inclusion, which is one radical inside another; and graphical addition where two or more radicals are superimposed upon each other. There is also more variation on the right side of the character, because there are more phonetic radicals which usually occur on the right, than semantic radicals which usually occur on the left.

2.1.1.1 The Semantic Radical

As described by Hsiao and Shillcock (2006), there are fewer semantic radicals than phonetic, which makes them more regular in Chinese characters: only 214 semantic radicals, as opposed to more than 800 phonetic radicals (Hoosain, 1991). There is undoubtedly a bias towards semantic processing in Chinese character decoding, which means that the default path of recognition is via semantic recognition (Williams & Bever, 2010: 603). The importance of semantic radicals is evident in the role that they play in identifying characters in a Chinese dictionary: to look up a character one counts how many number of strokes the semantic radical of the character has, then proceeds to a list of radicals with that stroke count and then consult an index list containing all the characters that contain that specific radical.

Williams and Bever (2010) confirm the importance of meaning in Chinese characters by displaying characters with either a blurred phonetic radical or a blurred semantic radical to native speakers of Chinese. The respondents took longer to name the characters with blurred semantic radicals as well as making more naming errors in the process.

An experiment by Hsaio *et al.* (2007) ratifies the role that semantic radicals play in Chinese character recognition. Research was conducted to investigate the cueing effects on Chinese character recognition, focusing on three variables: combinality, semantic transparency and cue location. Combinality refers to the number of characters that use specific semantic radicals. Thus, large combinality semantic radicals combine with a considerable number of characters and small combinality semantic radicals combine with only a few. Secondly, semantic transparency refers to how clear the relationship is between a character and its semantic radical. A transparent character would have a semantic radical that corresponds clearly to the meaning on the whole character level, while with opaque characters, the meaning of the semantic radical and the character would differ. Lastly, the cue location refers to the direction of the cue that triggers a meaningful response in the respondent.

Hsiao *et al.* (2007) then presented Chinese characters, specifically semantic-phonetic compounds where the semantic radical is on the left and the phonetic radical on the right, to native speakers for 150 milliseconds, whereafter the respondents had to choose whether the character was semantically transparent or semantically opaque. However, just before the Chinese character was displayed, a cue, which in their experiment is a black rectangle, was presented either to the left or right of the character. A no cue variable was also used. A right or left cue improves the processing of the corresponding segment that is displayed (Auclair & Sieroff, 2002). Thus in Chinese characters that consist of semantic-phonetic compounds, the cue on the left would improve processing of the semantic radical and the right cue would improve processing of the phonetic radical. This is important to note, because if one is to study the impact of Chinese radicals during the learning of Chinese characters, the location of the radicals need to be controlled to produce consistent results.

Hsiao *et al.* (2007) also found that characters that have a semantic radical with large combinality are more quickly recognized and identified with higher accuracy on semantic transparency. The transparent characters are also identified more quickly and more accurately. Furthermore, within the variables combinality and cue location, it was found that the response to small combinality characters was more accurate and quicker when the cue was on the left as against small combinality characters where the cue was on the right. However, with larger combinality characters where the cue was on the left, identification was slower and accuracy less compared to larger combinality characters where the cue was on the right. This shows that when cues on the left are given with characters that have small combinality, the focus shifts to the semantic radical and the character is recognized quicker and more accurately than large combinality characters, because there are fewer characters that interfere with the processing. Large combinality characters are less reliable and thus prone to slower identification with less accuracy. Therefore, in large combinality characters, the phonetic radical plays a bigger role in aiding identification of the character as a whole than it does in small combinality characters.

The effects of combinality and regularity of a semantic radical thus clearly impacts how a Chinese character is processed for meaning. The influence on recall and recognition will be discussed in section 2.1.2 later in this literature review.

2.1.1.2 The Phonetic Radical

Phonetic radicals provide pronunciation cues in semantic-phonetic compounds. De Francis (1989: 113) classifies phonetic radicals into the usefulness of the phonetic radical in predicting the pronunciation on the character level as follows:

1. completely useful phonetic (exact match)
2. generally useful phonetic (differs on tone)
3. contextually useful phonetic (differs on some aspects, such as rhyme)
4. useless phonetic (no significant relation)

Character	Pronunciation	Phonetic Radical	Pronunciation	Usefulness
洋	Yáng	羊	/yáng/	Completely
喝	Hē	曷	/hé/	Generally
河	Hé	可	/kě/	Contextually
馔	Zhuàn	巽	/xùn/	Useless

According to De Francis (1989: 113) only 25% of characters fall within the "completely useful phonetic" category. Fan *et al.* (1984) also claim that 26% of phonetic radicals contribute as reliable cues to the pronunciation of a character. The other categories of De Francis accounts for 17%, 24% and 33% respectively. The remaining 1% is attributed to simple characters which are non-compound characters. Hsiao & Shillcock (2006) analysed the 3027 most frequent semantic-phonetic compounds in terms of their regularity, which put characters into three categories: regular, semi-regular and irregular. Completely regular characters refer to instances in which the phonetic radical and pronunciation of the character are exactly the same. This is similar to De Francis' category number one (De Francis, 1989), where the radical is classified as completely useful. Semi-regular characters refer to the same underlying pronunciation with the phonetic radical, but differing in tone and the classification of irregular combines De Francis' third and fourth categories into one. However, Hsiao and Shillcock (2006) also break the irregular category down into three sub-categories: alliterating, rhyming and radically irregular. Alliterating and rhyming refer to instances in which the pronunciation of the phonetic radical either alliterates or rhymes with the pronunciation of the character. Radically irregular would refer to instances in which the pronunciation of the phonetic radical and that of the character have no relation at all.

As with the semantic radical, one has to understand the differences in relationships between the phonetic radical and the pronunciation of the radical and that of the

character. This allows studies to be conducted with a consistent set of characters. Hsiao & Shillcock (2006) found in their data that 33.5% of semantic phonetic compounds are regular, 14.7% semi-regular and 51.8% are irregular. They also go further in their analysis by explaining that the regular and semi-regular groups should be seen as identical, because of two reasons: first, the tones in continuous flowing speech is not in strict correlation to the word, but rather follow a contour over neighbouring words (Xu, 1994; 2001) and secondly, Chen *et al.* (2002) found in a priming experiment that the syllable is the primary planning unit when it comes to naming Chinese characters. This means that when a Chinese character is named, the syllable is first constructed whereafter the tone is added as an additional identifier. For these two reasons, Hsiao & Shillcock placed their two categorizations, regular and semi-regular, into one, increasing the number of characters with useful phonetic radicals closer to 48.2%. In the irregular categorization, Hsiao & Shillcock (2006) place three categories: alliterating, rhyming and radically irregular which means that the radically irregular character set only makes up 23% of their data.

This disparity in phonetic radical reliability at character level is due to the socio-historical development of the Chinese language (*The Wisdom of Chinese Characters*, 2009). Even though phonetic radicals are not consistent in predicting the pronunciation at character level, there are various other factors that determine the pronunciation of a Chinese character, of which one is frequency. That the frequency of a character plays a role in the speed of naming a character, was documented by Seidenberg (1985) when he found that low frequency characters were named faster than simple characters (characters with no other radicals which make up 1% of Chinese characters). This suggests that familiar, or high frequency, Chinese characters are read as a logographic whole, because the reader is more familiar with the word, due to its higher frequency (Zhou & Marslen Wilson, 1999). Therefore, little decomposition happens in the process of accessing phonetic radicals in high frequency words. When lower frequency words arise, the reader/speaker seeks phonetic information contained within the character to name the character. In choosing materials for a research study to test recall of Chinese characters, preference is given to characters that are homogenous in frequency.

Further interactions exist with the phonetic radical on the character level regarding regularity and consistency. The regularity effect is similar to transparency, as mentioned earlier, in that the phonetic radical of regular character would be similar to the pronunciation, excluding tone, on the character level. On the other hand, the phonetic radical of an irregular character would be completely different to the pronunciation of the character (Lee *et al.*, 2005).

Consistency refers to a phonetic radical's consistency when it is combined with other characters. For instance, the phonetic radical 由 which is pronounced as /yóu/, is mostly consistent, because only two out of the twelve characters that use 由 as a phonetic radical are pronounced differently, regardless of tone difference (Lee *et al.*, 2005).

The consistency of phonetic radicals plays a role in the naming performance of high and low frequency characters. The regularity effect, on the other hand only applies to low frequency characters (Seidenberg, 1985; Lee *et al.*, 2005; Hue, 1992). This means that accurately naming Chinese characters is more likely to be influenced by the pronunciation of other characters that have the same phonetic radical than the regularity between the pronunciation of a Chinese character and the pronunciation of a phonetic radical (Lee *et al.*, 2005). Regularity only aids in the ability to accurately name low frequency characters.

In conclusion, influences the accurate naming of a Chinese character depending on the presence of the variables frequency, consistency and regularity.

2.1.2 Chinese Radicals in Word Recognition and Reading Development

Although radicals aid in reading Chinese characters, some radicals provide clearer information on the meaning and pronunciation of the character as a whole. Young children performed better in recognizing morphologically transparent characters and this was especially apparent when unfamiliar words were presented to them (Anderson & Shu, 1997). Another significant result from this study shows that conceptually simple words are more easily recognized from their radical constituents. Furthermore, the same study established that poor readers, even when they had knowledge of the meaning of radicals, typically do not make correct inferences, while good readers can infer unfamiliar, but

transparent characters. Thus, metalinguistic awareness plays a significant role in reading Chinese characters (Anderson & Shu, 1997). Another study on Chinese children by Packard *et al.* (2006) shows that explicitly teaching orthographical and morphological structures improved the ability of the children to copy characters as well as write them from memory.

In line with the performance of young learners, the explicit instruction of radicals in characters has also been shown to improve long-term retention of vocabulary items in adult learners (Dunlap *et al.*, in press) and in beginner learners of Chinese as a second language (Taft & Chung, 1999). The latter study also confirmed that showing the radicals on the first presentation of the character was the most efficient method when teaching Chinese to beginners. Wang *et al.* (2004) corroborated findings from other researchers that explicit instruction of the function of semantic radicals noticeably improved the ability of first year learners of Chinese as a foreign language to extract semantic information from the characters. They found that high frequency radicals provided more appropriate inferences of meaning than low frequency radicals. These frequencies were calculated from within the participant's prescribed Chinese textbook. Another notable result from the study was that after instruction on low frequency radicals, the learners improved more when learning the function of the semantic radical as opposed to learning the function of the semantic radical in high frequency radicals. A positive correlation between radical application skills and word acquisition was also found in a study that researched radical knowledge developmental trends in non-native learners of Chinese (Helen & Ke, 2007).

A cross-linguistic study shows that in both English and Chinese, words are initially read and learned as logographic units (Suk-Han Ho & Bryant, 1997). This means that learning to read Chinese characters and alphabetic scripts are initially not different. In an alphabetic script, however, both phonetic and morphological information are more readily available than in Chinese where, when reading beyond the logographic phase, it becomes apparent that skilled readers not only rely on radical information to process deeper information, but also relieve cognitive load by not remembering each character as a logographic whole, but rather as a combination of its constituent radical components (Suk-Han Ho & Bryant, 1997).

2.2 Lexical Models for processing the Chinese script

The influence of radicals as sub-lexical units in reading and recognizing Chinese characters produce additional complexities that do not arise in an alphabetic script. Taft & Zhu (1997) proposed a multilevel interactive-activation and competition (IAC) framework for processing Chinese words. In this framework, there is a hierarchy of Chinese orthography, from strokes, to radicals, to characters and then multi-character words. When a word or character is processed, it enters into the processing route through the lowest orthographical unit, usually strokes, and is then passed onto other levels of units, radicals, character and words, where phonological and semantic information is linked. Thus, a lexical unit is affected by the properties of its components.

There is, however, a difference in processing Chinese as opposed to processing English, for example. English has direct grapheme to phoneme correspondence rules, but Chinese does not. The grapheme in Chinese maps to a morpheme with semantic and phonological information. When reading English, phonological information is much more readily accessed in what is called cascade-style processing. This means that when reading a word, even before completing the whole word, phonological information is already accessible via pre-lexical access thanks to grapheme-to-phoneme mapping, and thus already within the mental process of word recognition (Seidenberg & McClelland, 1989). Chinese, however, works differently. The phonological and semantic information can only be activated once the orthographical information has completely entered the process of word recognition. This is called threshold-style processing (Perfetti *et al.*, 2005).

Liu *et al.* (2007) found that in second-language learners in the first year of learning Chinese at university and during the early stages of Chinese character learning, the threshold of orthographical activation decreased at the end of the second term, compared to the end of the first term results. Learners got used to the different orthography which meant that semantic and phonetic information were more readily accessed at the end of the second term.

Another explanatory model of Chinese word processing, the Parallel Distributed Processing (PDP) model involves a more abstract approach, in that it doesn't specify a

hierarchy of orthographical features (Seidenberg & McClelland, 1989). It has three layers or groups called input, hidden units and output. When a word is read, it enters via the input layer, which is usually the orthography of a language. Here the process then has to go the output layer so that it be pronounced or understood for meaning. When the word /gave/ is read, how does the brain determine how it will be pronounced? Parallel distributed processing claims that this is determined by weights, or importance given to phonemes in relation to other words that have already been learned. If a learner has learned how to pronounce the word /save/, then he or she would have a good chance of pronouncing /gave/ correctly due to the similarity of /ave/. However, if the learner has only learned /have/ which has a different pronunciation for /ave/, then the learner would pronounce /gave/ incorrectly. Parallel distributed processing is a statistical solution to exceptions and rules in lexical items. The weights or statistical memory are the hidden units (Seidenberg, 2005).

Lexical processing occurs in parallel fashion, in that different activation among orthography, phonology and semantics happen at the same time, as well as being distributed, meaning that these processes occur in different units. An fMRI study confirmed that in reading Chinese, the interaction between orthographic, phonological and semantic systems are processed concurrently in different parts of the brain (Kuo *et al.*, 2004).

English is usually categorized as spelling-to-sound system, or an orthographic to phonetic system. However, Chinese has additional radicals that convey semantic information in its orthography, thus Chinese is seen as a spelling-to-meaning system, or orthographic to semantic. Yang *et al.* (2006) tested these two systems using the PDP model, also known as the triangle model, which has connections between orthography, phonology and semantics, and found that, in contrast to English, owing to the sub-lexical information in Chinese, the relation of spelling to meaning is learned more rapidly than spelling to sound. The importance of embedded meaning within Chinese orthography thus forms an integral part of reading Chinese and leads to unique characteristics, such as having threshold-style processing and quicker learning of spelling-to-meaning connections than spelling-to-sound connections, when compared to an alphabetic script.

Lee *et al.* (2005) also documented the effects of consistency, regularity and frequency on naming Chinese characters and found that both the IAC and PDP models could account for all three of those effects.

2.3 Vocabulary in Foreign Language Learning

Vocabulary is an essential part of language, but one needs to ask where it fits into the process of foreign language learning. As mentioned before, Nation (2007) put forward a systematic approach to language learning in four strands, namely meaning-focused input, meaning-focused output, fluency development and language-focused learning. These four strands can apply to both language teaching and informal language learning.

Meaning-focused input focuses on reading and listening. The goal is to understand and gain knowledge through understandable input. This is similar to Krashen's input hypothesis (1982) that postulates that meaningful comprehensible input should be given priority and that in learning a new language, the input should be just above the learner's current level of understanding.

Meaning-focused output focuses on speaking and writing. Here the learners aim to be understood and get their message across. This aids the learner and serves three functions put forward by Swain (1985): the noticing/triggering function, the hypothesis-testing function and the metalinguistic reflective function. These three functions, in summary, aim to make the learner aware of gaps within their knowledge of the language, allowing them to test hypotheses and get feedback as well as figuring out how to talk about language itself, thereby learning about the language as an entity.

Fluency development involves all uses of language, reading, writing, listening and speaking and the aim is to improve the knowledge of language the learner already possesses. This includes activities such as speed reading, repeated retelling and listening to easy stories.

Finally, there is language-focused learning. This involves intentional learning of language features, such as grammar, spelling, vocabulary and discourse. The goal is to learn language items with a focus on form as well as meaning. Activities typically include

pronunciation practice, studying vocabulary with flashcards, translation and memorizing dialogues. Deliberate learning increases implicit knowledge and helps with later language learning. Nation (2007) recommends that when learning a large number of vocabulary items, that these words should be spaced further and further apart. Learning vocabulary in such a way uses the spacing effect as a beneficial cognitive phenomenon, which will be described later in this literature review. The present thesis focuses on language-focused learning, specifically the deliberate learning of vocabulary.

Deliberate learning of vocabulary has been shown to be more efficient than incidental learning when learning new vocabulary items, where learners can learn up to 100 bilingual word pairs in an hour (Nation, 1980: 18). The retention rates of deliberately learned vocabulary are also higher compared to acquiring vocabulary under incidental conditions (Hulstijn, 2003: 373). The widespread acceptance and use of communicative language teaching has cast deliberate learning in a very negative light. However, as Nation (2007) has pointed out, language-focused learning should be part of a balanced approach to language learning. Acquiring vocabulary only through implicit means is not sufficient (Laufer, 2005).

While deliberate learning of vocabulary has been proven to be efficient, the question is whether this is also an effective way of learning. Elgort's (2011) study to answer this question found that out-of-context deliberate learning of words can be effective as well. Priming experiments established that vocabulary items learned in out-of-context deliberate conditions are stored in a manner similar to existing L1 and L2 lexical items. However, the same way that Nation (2007) indicated that language-focused learning is only one strand of a balanced approach, so Elgort (2011) warns that only using deliberate learning of vocabulary is not enough. Further contextual learning is needed to improve the processing of a lexical item and fully acquire the complex relationships of meanings in and between words. Learning vocabulary in a deliberate manner provides advantages for establishing deeper processing of vocabulary when lexical items are then subsequently encountered in meaningful contexts.

Beheydt (1987: 57) uses the term semantization for the complex process of acquiring a word and its meaning. He stresses that meaningful contextual information, such as

morphological information and sentence context, is vital in the semantization process as it adds additional anchorage for the learner to attribute meaning to the vocabulary item. When one looks at the IAC and PDP models for word processing, this seems to hold true, as more connections between the various units increase recognition, because of the parallel and distributed nature of these models. Furthermore, specifically Chinese with its threshold-style processing, increasing the amount of information that a learner can access, lowers the threshold limit, as was seen in the study by Liu *et al.* (2007) where adult second language learners of Chinese accessed the phonological and semantic information quicker after the second term had passed.

Henriksen (1999: 304-307) also terms vocabulary acquisition as a semantization process and proposes three dimensions of vocabulary development:

1. Partial to precise knowledge: this is the process of defining the boundaries of meaning, moving from a partial to a more precise definition.
2. Depth of knowledge: this refers to the knowledge aspects of lexical competence, which are intensional meanings and sense relations to other words, such as paradigmatic links in synonyms and antonyms, as well as syntagmatic relations, which includes collocation restrictions.
3. Receptive to productive control: vocabulary is either receptive or productive and the control between them is a continuum.

This thesis will focus on the relationship between dimensions one and two in which the student learns the reference of a word and also develops paradigmatic relations and intensional links between vocabulary due to deeper processing of Chinese orthography, specifically Chinese radicals. Dimension one and two are beneficial, because learning the deeper relationships between words and increasing lexical knowledge aids in establishing a precise word meaning in dimension one (Henriksen, 1999: 311).

Both implicit and explicit processes account for different ways of acquiring vocabulary. Implicit knowledge, which can be gained through incidental learning activities such as extensive reading and repeated exposure to the target language, contains sound and pattern recognition, while explicit knowledge contains the semantic references which can

be gained through deliberate learning activities and direct processing strategies such as semantic elaboration or mnemonics along with utilizing cognitive phenomena such as spacing and testing effects (Ellis, 1995).

2.4 The Spacing Effect

The spacing effect is a robust and well-documented effect within cognitive psychology, with a history of more than hundred years in research. It started with Ebbinghaus (1885) who found that when learning syllables over three days with fewer repetitions yielded the same recall results than learning syllables directly after each other with more repetitions on the same day.

Various authors have done reviews on the spacing effect (Hintzman, 1973; Hintzman *et al.*, 1975; Melton, 1970; Thalmeimer, 2006) and the spacing effect has been shown to be a verifiable and repeatable phenomenon within psychology (Melton, 1970). It is also known as distributed practice, spaced presentation and spaced repetition. Various studies have shown that learning vocabulary using the spacing effect improves recall (Baturay *et al.*, 2009; Bahrick *et al.*, 1993; Pavlik *et al.*, 2008; Bloom & Shuell, 1981; Kornell, 2009).

The spacing effect is not only limited to word lists, but also aids children in learning educational concepts, such as food chains within nature, by using basic and complex generalization (Vlach & Sandhofer, 2012). Scheduling rehearsal for music practice in a distributed pattern also produced better results than immediate repetition (Stambaugh, 2009).

The robustness of the spacing effect was also observed in an independent long-term study using the same subject spanning nine years of learning Spanish-English words (Bahrick *et al.*, 1993). Researchers found that the retention of knowledge of 13 repetitions spaced 56 days apart was comparable to 26 repetitions spaced 14 days apart. A study done by Kornel (2009) similarly confirmed that spacing flashcards, in contrast to massed presentation, improved recall of the material.

2.4.1 The Cause of the Spacing Effect

Current research on the spacing effect looks at the exact cause of the effect, since this is still uncertain. Two main theories have surfaced, namely the deficient processing and study-phase retrieval theories. Deficient processing theory states that when someone learns material that is massed, i.e. repetitions following each other immediately, the learner has a false sense of knowledge of the materials that has been learned, thus less effort is given to learn it in subsequent repetitions. Whereas in spaced repetitions, the memory has faded and the learner puts more effort into remembering information (Greene, 1989). Study-phase retrieval theory postulates that when a learner encounters a repetition it activates previous items stored in memory and the contextual change between the repeated items is encoded (Greene, 1989; Verkoeijen, 2005; Hintzman & Block, 1973; Hintzman *et al.*, 1975). Thus, more contextual elements and retrieval cues are available for recall than in massed presentation. These accounts however refer to free recall, where items are learned and participants are asked to recall what they remember. There is another type of recall that has cues, called cued-recall. In cued-recall tests, a yes/no recognition task is given in which a participant has to respond by confirming whether or they have previously encountered the stimulus or not. Another example of a cued-recall test is the use of word pairs and this is usually associated with foreign language vocabulary learning methods.

Cued-recall has different interactions with the spacing effect, because encoding is more likely to occur between pairs or cues than contextual information in a free recall test. Greene (1989) put forward the voluntary rehearsal theory in which he explains that the participant directs less attention towards the items in massed presentation which is why spaced items are recalled better due to more attention given to each item. This account however has been challenged, as studies have found that in an incidental learning task where participants focused on semantic analysis, a spacing effect was found (Challis, 1993). This finding opposes the idea that Greene (1989) put forward in that voluntary attention is not necessarily the catalyst for the spacing effect to occur, as in occur under incidental conditions as well. Challis (1993) also posited a semantic priming account for cued-recall in the spacing effect, which states that when semantic priming is prevented in pairs, no spacing effect will occur. This happens, for example, when focusing on the

structural features of words instead of the semantic features of words. Priming reduces the processing needed for the target item, thus adding intervals between repetition, reduces the impact of the priming and adds more processing to the target item during encoding.

Some circumstances have been found where the spacing effect does occur when semantic priming is prohibited, for example when participants were forced to focus on graphemic properties of non-words, such as counting how many letters the word has (Russo & Mammarella, 2002). After the Russo & Mammarella (2002) findings, they proposed that the spacing effect in cued-recall occurs because of the transfer-appropriate processing approach in memory tasks (Kolers & Roediger, 1984). This states that two conditions need to be present to produce a spacing effect: first, the type of items on the test and the type of items while studying must be predominantly compatible, and second, there has to be some form of priming that reduces the processing on the second occurrence in massed presentation. An example of condition two would be a cued-recall task that uses foreign language vocabulary word pairs in which the first word is a foreign language word and the recall test is an English translation. If the presentation is massed, then the learner still has some form if priming influence, which is triggered by the foreign language vocabulary item. Therefore, the learner puts lets effort into establishing a stronger link between the word pairs. If it is spaced further apart, the priming fades and more processing is needed to recall the word pair.

It is thus important to take into account the conditions of transfer-appropriate processing approach as it might impact the efficacy of the spacing effect.

2.4.2 Expanding versus Fixed Intervals

Research involving the spacing effect usually takes place with a specified set of items. For instance, when a set of 10 words is to be learned, they are interspersed among other non-repetitive words. This means that words to be learned are repeated, but they are spaced between non-repeated words and not massed. The intervals are equally spaced (Greene, 1989; Hintzman *et al.* 1975). An example of this for the word "apple" would be:

Apple; Cup; Book; Apple; Paper; Pen; Apple; Bottle; Laptop; Apple

Looking at the example above, this is called a fixed interval spacing effect, because the spacing between repetitions is the same. The word *apple* will always occur after two words have been inserted between it. Therefore it can be described as having an interval of two words.

Another type of interval for the spacing effect is one that expands upon each repetition. For instance, taking the above example again with the word and implement an expanding interval:

Apple; Cup; Apple; Book; Paper; Pen; Apple; Bottle; Laptop; Box; Light; Sun; Apple

The list above increases the delay of the word apple on an expanding interval of two per repetition. So the word *apple* would appear after 1, 3 and 5 words have been placed. In contrast to the spacing effect, massed presentation would have zero intervals, 0-0-0.

Apple; Apple; Apple; Apple;

Research into the benefits of expanding versus fixed interval spacing effects prove to be varied. Cull *et al.* (1996) found that expanding intervals outperformed fixed intervals when testing name-surname associations. Karpicke & Roediger (2007) found that in learning word pairs, that short-term retention was better using expanding retrieval, but long-term retention was better under a fixed interval. Face-to-name recognition was also better under a fixed interval spacing effect (Carpenter & DeLosh, 2005). Balota *et al.* (2007) did a critical review on academic literature concerning expanding and fixed intervals. They found conflicting results as there was a tendency for expanding intervals to perform better in the short term, but worse in the long-term compared to fixed intervals. This irregularity was also found by Karpicke & Roediger (2007).

It is still uncertain which intervals are best suited to take advantage of the spacing effect. Both intervals, however, can be used for spacing effect research, as both expanding and fixed intervals create a spacing effect and are thus an improvement on massed presentation.

2.5 Spaced Repetition Programs

Spaced repetition programs are digital applications that not only utilize the spacing effect, but also maximize the effect of the forgetting curve, which was also first documented by Ebbinghaus (1885). This means that when words are learned in a spaced manner, rather than massed, the intervals between each repetition is dependent on the forgetting curve. The forgetting curve is an optimal curve before a word, or other item learned is forgotten. So, repeated presentation of a word in spaced repetition occurs right before the word is about to be forgotten. The forgetting curve corresponds to an expanding interval spacing effect, because each time a repetition is seen or retrieved, it strengthens the memory of it. Wozniak (1995) set out to test the limits of the forgetting curve by utilizing the spacing effect and created a program called *SuperMemo* which uses complex algorithms that time the review of flashcards for efficient learning.

The *SuperMemo* algorithms are the basis for a number of widely used flashcard programs that utilize spaced repetition, such as *Anki* and *Mnemosyne*. These programs are extensively used within informal language learning communities, but also serve to teach other materials, for example, *Anki* was used by a recording-breaking contestant, Roger Craig, in the American trivia show *Jeopardy!* to memorize vast amounts of information (Baker, 2011). *Anki* and *Mnemosyne* will be described in detail in Chapter 3.

Flashcards also incorporate another cognitive phenomenon known as the testing effect or retrieval practice. This beneficial effect occurs when learners test themselves by using a cue and answer method, similar to the front and back sides of a flashcard. The retrieval of the answer, the test itself, strengthens the memory of the answer to the cue (Roediger & Karpicke, 2006). This effect leads to better long-term retention and is more beneficial than merely restudying material (Roediger & Karpicke, 2006). For example, when studying word pairs, it would be better to learn them via a flashcard method, because this invokes the testing effect, rather merely looking at the word pairs together. Unlike other flashcard applications, spaced repetition programs, never drop out flashcards, as the card will continuously be reviewed, unless the learner explicitly removes the flashcard from the deck. Every card in a spaced repetition system will eventually be reviewed again,

which is beneficial as was confirmed by another study done by Roediger & Karpicke (2007) in which they showed that repeated testing of recalled items had a large positive effect on long-term retention. A study by Kornell & Son (2009) investigating responses to the testing effect showed that students prefer testing themselves, rather than restudying material, not because of the belief that it improves learning, but in order to diagnose their learning.

Spaced repetition programs at present do not accommodate the unique challenges and attributes of the Chinese script. Not enough research has been done on Chinese character acquisition by using spaced repetition systems. This could be because spaced repetition systems are created to cater for many languages and thus do not take into account the intricacies and idiosyncrasies of the script of each language.

A study (Pavlik *et al.*, 2008) was done using an optimal practice schedule to learn basic facts that also utilize the spacing effect. What makes this study unique from other spacing effect research was that as an additional measure, information on radicals was included as precursor for character recognition. The researchers found that within this practice schedule, learning only radicals provided better results than students learning only characters. Although this shows a preliminary influence of giving students explicit information on radicals within a spacing program, a flashcard approach was not used and Chinese vocabulary acquisition was not the main focus of the study.

Some research has been done on computer-aided instruction programs for Chinese characters in general. For example, Hsueh (2005) developed a Chinese Radical and Character Tutorial application with the focus on using hypermedia. *Skritter* (Skritter.com) initially developed by students from Oberlin College in Ohio, is now a popular online Chinese writing application that also uses spaced repetition algorithms, including some parts of the *SuperMemo* algorithms for spacing words, to schedule words to be reviewed. They offer a unique writing system, often using touch screens and/or graphic tablets, that aid the learner in writing Chinese characters by hand. Web-based spaced repetition of foreign language vocabulary has also been shown to increase retention of vocabulary (Baturay *et al.*, 2009).

A study by Nakata (2008) found that in learning English vocabulary, paired word lists performed worse than a computer-implemented spacing algorithm called the low-first method (Mizuno, 2000), whereas traditional flashcards only had a limited advantage over lists and no significant advantage over the computer implementation. It should be noted that there were limitations within the study, in that only ten words were learned and students may not have been familiar on how to use flashcards effectively.

2.6 Conclusion

The Chinese script offers a unique perspective in the manner in which orthography affects reading and word identification. Chinese radicals form part of the majority of Chinese characters, called semantic-phonetic compounds, which have a strong effect on how Chinese characters and words are processed. The existence of the sub-lexical units, called Chinese radicals, produces varied results in word recognition, naming and priming. Various factors need to be considered when interacting with Chinese characters and radicals: frequency, combinality, regularity, consistency and transparency.

	Semantic Radical	Phonetic Radical
Regularity		Regular characters named faster & more accurately. Especially aids in naming of low frequency characters.
Consistency		High frequency characters are sensitive to consistency. Consistent characters named faster & more accurately
Transparency	More transparent characters identified quicker and more accurately	

Frequency of Character		Higher frequency characters receive less decomposition
Frequency of Radical	High frequency radicals provide more appropriate inferences, however in low frequency characters, the function of semantic radicals is better learned.	
Combinality	High combinality named quicker & more accurately	In large combinality of the semantic radical, phonetic radicals play a bigger role in decomposition.

All these variables interact with word identification and need to be carefully controlled when choosing materials to use in recognition tests of Chinese characters, especially semantic-phonetic compounds. Due to the complex nature of the Chinese script, the interactive activation and competition model and parallel-distributed model for word identification both account for the interactions with variables in the Chinese orthography and how it affects reading Chinese characters. It should be noted that Chinese works differently than an alphabetic language in the way it is read. Chinese has threshold-style processing, while an alphabetic language has cascade-style processing. This adds another dimension to Chinese word recognition, as the mapping between orthography, semantics and phonology is more dependent on orthography and learning the connections between it and the two other parts of a lexical item: semantics and phonology.

The spacing effect is a robust cognitive phenomenon, but its exact cause is still under research, as is evidenced by the frequent change of theories on the processes involved in free- and cued-recall. However, its use in improving recall of vocabulary is positive, both in fixed and expanding intervals. It can be used in spaced repetition systems that use flashcards to complement foreign language learning as form of language-focused learning.

Specific research into the combination of spaced repetition systems and Chinese vocabulary acquisition is scanty, while both the spacing effect and Chinese orthography separately are well researched topics and their effect on learning vocabulary items have been demonstrated as a positive one.

Chapter 3: Developing Spaced Repetition Systems

In order to test the interaction between the spacing effect and the addition of radicals in improving Chinese character recall, both a control and experimental application were designed. The ADDIE (Analysis, Design, Development, Implementation and Evaluation) instructional design model was used to guide the development, design and experiments. This chapter will document the process of analysis, design and development, while chapter 4 will document the implementation and evaluation of the results of experiments. Therefore, in the first section (3.1), two spaced repetition systems will be investigated in terms of their design and implementation. Included in this section is also an examination of the objectives and goals of the application used in this study that need to be satisfied for both the control and experimental versions. Thereafter, the section on design (3.2) describes how these applications were designed and the final section (3.3) documents the development process.

3.1 Analysis

The two applications that were created are based on a type of program called spaced repetition systems. I first needed to understand how spaced repetition applications are designed and how they work before developing the applications used in the research. Only certain elements of spaced repetition systems were used in both the control and experimental applications. Two popular applications were considered for investigation namely *Anki* and *Mnemosyne* as both use the spacing effect and flashcards to review vocabulary or other items that are used for learning through flashcards. Both programs are freely available for download and on both Windows and Mac operating systems and both applications are open-source. In this study, *Anki* version 1.2.8 and *Mnemosyne* version 1.2.1 are described. After the description of how recent spaced repetition systems are designed and how they work, goals and objectives will be presented for the present research. These goals and objectives will inform the process of differentiation for the control and experimental application in this study.

Nakata's (2011) critical review of flashcard software did not include *Anki* and *Mnemosyne*, because one of the criteria for the review was that it should have been featured in academic literature. Although *Anki* and *Mnemosyne* have not been reviewed in academic literature, this researcher chose to focus on these two applications in this study due to observations of their popularity among informal language learners as well as Branwen's (2012) similar observation in that *Anki* and *Mnemosyne* are popular flashcard applications that use spaced repetitions (Branwen, 2012).

3.1.1 Spaced Repetition Systems

Spaced repetition systems are applications that utilize the spacing effect to effectively calculate inter-repetition intervals for the learner based on their responses to their knowledge of a word. Not all spaced repetition systems use a flashcard approach, for example in *Skritter* (Skritter.com, 2012), learners are prompted to write characters, instead of recalling word pairs. A flashcard approach, however, is the choice for *Anki* and *Mnemosyne*.

In *Anki* and *Mnemosyne*, the learner has the ability to view a deck of flashcards, usually with a thematic theme, such as trivia or foreign language vocabulary. There are pre-built decks available that have been created by the community and other learners which can be downloaded for free. The learners can create their own deck of flashcards as well. These words are then entered into the spaced repetition system at a pace set by the learner. The default for *Anki* is 20 new words a day and *Mnemosyne* operates at an ad-hoc basis, but gives preference to words that need to be reviewed that day.

The flashcards are repeated on expanding inter-repetition intervals that utilize the forgetting curve for optimal spacing (Wozniak, 1995; Ebbinghaus, 1885).

3.1.1.1 Analysis of Design

Anki and *Mnemosyne* are designed as desktop applications. They have a small form factor and do not fill up much screen space. Both have a similar approach in presenting flashcards to the learner, as is illustrated below:

Figure 2: Mnemosyne version 1.2.1 on the left and Anki 1.2.8 on the right both running on Mac OSX

The top part in this screenshot represents the front of the flashcard while the back of the flashcard is shown in the bottom part. In *Anki*, the *show answer* button changes into difficulty ratings, the usage of which is explained in the section on spacing algorithms (3.1.1.2). In *Mnemosyne* the grading buttons become clickable after pressing the *show answer* button.

After the presentation of the back of the flashcard, the learner then has to decide how well they remembered the word. The self-grading buttons help the program to determine how far in advance to space the next repetition of the flashcard. There is a slight difference in the way *Anki* and *Mnemosyne* allow the learners to grade themselves and how the spacing distance is determined.

Anki has more transparency and shows the learner when a particular flashcard will reappear. This action is dependent on how well the learner grades himself: the buttons for grading are Again (immediately put back onto the deck), Hard, Good and Easy. The first grade, Again, is seen as a fail grade, because the learner could not recall the word. In *Mnemosyne*, the grading ranges from zero to five, where five is instant retrieval. Zero and

one are seen as fail grades and from two onwards the interval increases as the grading increases. After choosing the grade, the next flashcard is presented.

At the top of both applications is a toolbar that allows for quick actions within the application, such as creating flashcards, checking statistics and searching for cards.

At the bottom of both applications are details about the current deck of flashcards. In *Mnemosyne* the toolbar shows how many cards are scheduled for review, then how many have not been memorized and then finally how many cards in total are in the deck. *Anki* is very similar, but does not show the total cards in the deck and adds a timer to the display.

3.1.1.2 Spacing Algorithms

Both *Anki* and *Mnemosyne* use modified algorithms that are based on *SuperMemo*'s second iteration. The scope of this thesis will not go into too much depth regarding the mathematical computation of the algorithm, but rather explain how Wozniak (1995) utilizes the forgetting curve to create optimal spacing. *Anki* and *Mnemosyne* however changed some aspects of the algorithm and these are described as well.

3.1.1.2.1 SM-2

SM-2 is the short name given for *SuperMemo*'s second version of an algorithm that determines expanding spaced repetition intervals. Initially for the first two repetitions, the values are set at one day and then six days. After this, the interval is determined by the easiness factor and the graded response received from the student. The easiness factor is the main variable for affecting how far into the future a flashcard must be spaced. Each card starts with a 2.5 easiness factor. When a graded response is given, a new easiness factor is determined which is based on the existing easiness factor as well the graded response and other algorithmic constants that Wozniak (1995) developed. This allows the inter-repetition intervals to change based on the learner's knowledge of the flashcard. If for some reason a learner struggles with a card, it would be graded low and subsequently the easiness factor would decrease allowing the card's next repetition to be presented earlier (Wozniak, 1998).

3.1.1.2.2 Algorithms used by *Anki* and *Mnemosyne*

Initially, *Anki* used a more advanced version of *SuperMemo*'s algorithms, but decided to fall back to SM-2, due to it being simpler, more intuitive and predictable for learners (*Anki*, 2012). Advanced *SuperMemo* algorithms take into account more variables, such as calculating the difficulty of a card as well as the difficulty of related cards. *Anki* found that if a user is not consistent in his studies, the more advanced algorithms either produce repetitions too quickly or too far ahead (*Anki*, 2012).

Currently, *Anki* has made slight changes in the use of SM-2, such as changing the initial intervals of one and six days to one-three-five and seven-nine days depending on the quality of the initial graded response from the learner. This was chosen, as the developer of *Anki* puts an emphasis on an initial learning stage. The initial learning stage refers to a stage in *Anki* that helps the learner with initial acquisition of the flashcard item, before merely just reviewing the flashcards. Thus, the initial intervals are closer together to aid this learning, before repetitions solely focus on just reviewing the flashcards. The idea of a learning stage is also taken further, in the case when a learner successively fails to recall a card for which the inter-repetition interval is less than twenty-one days, the card's easiness factor does not decrease. Also, as is shown in the design section, *Anki* uses only four grading options, with the final grade option being more aggressive in spacing than SM-2 (*Anki*, 2012).

Mnemosyne is more closely related to the original SM-2 algorithm and also opts to use the SM-2 version due to the increasing complexity of later *SuperMemo* algorithms. The only changes that the developer of *Mnemosyne* implemented were modifications to early and late repetitions as well as adding a bit of randomness to the algorithm (*Mnemosyne*, 2012).

3.1.1.3 Features

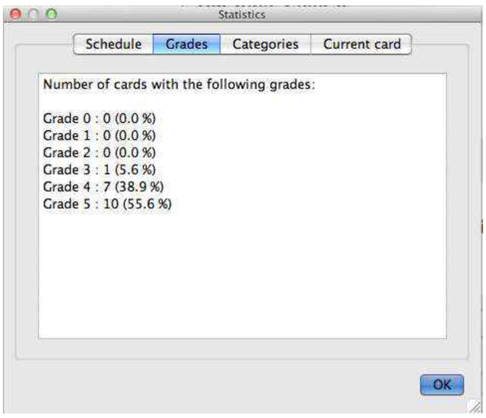
Nakata's (2011) analysis of flashcard software, includes a list of features that flashcard programs should have namely flashcard creation, multilingual support, multi-word units, specific types of information, support for data entry, flashcard sets, presentation and retrieval modes, increasing retrieval effort, generative use, block size, adaptive sequencing and expanded rehearsal.

Anki and *Mnemosyne* have most of those features, except for generative use and increasing retrieval effort. Generative use refers to automatic generation of flashcard information, for instance, placing a word into the context of a sentence automatically. Increasing retrieval effort is based on the retrieval effort hypothesis that states that flashcard retrieval should increase in difficulty as repetitions increase (Bjork, 1994, 1999 and Pyc & Rawson, 2009). For instance, when the first review of a word occurs, the flipside of the flashcard has options to choose the correct answer. Subsequent repetitions could, for example, increase options given to the learner and then later remove all options.

Only one flashcard program in Nakata's (2011) review had increasing retrieval effort and no flashcard program had generative use. Thus, when compared to other flashcard programs, *Anki* and *Mnemosyne* prove to be feature-rich and of sound design.

Both *Anki* and *Mnemosyne* have the ability to space flashcards, which according to Nakata (2011) which falls under the features of adaptive sequencing and expanded rehearsal. In addition, both *Anki* and *Mnemosyne* have other features worth noting.

Graphs and statistics are available in both applications. These give the learner insight into their deck and how the cards are spaced, among other statistics such as retention rates and time durations spent on the application. The ability to create new cards differ between *Anki* and *Mnemosyne*. *Anki* has more options, such as the ability to change the layout and adding cloze sections. Both *Anki* and *Mnemosyne* also have the ability to add pictures and sound in order to improve learning.



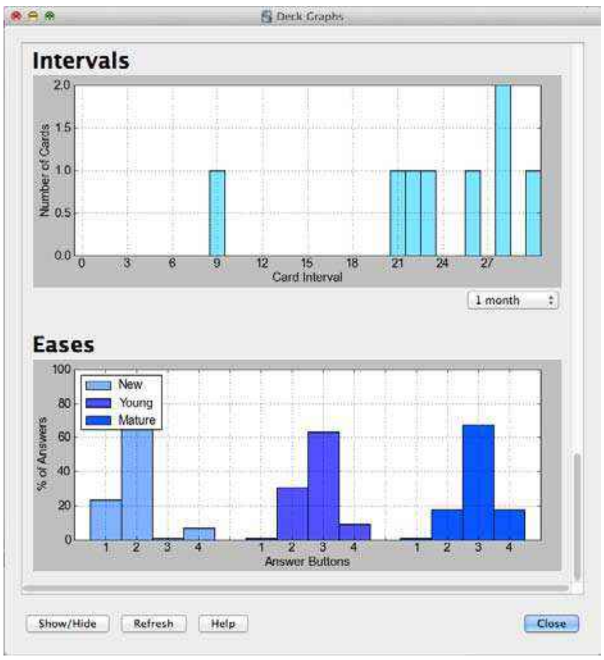


Figure 2: Various statistics as viewed in Mnemosyne and Anki

Anki has an advantage over *Mnemosyne* in terms of flashcard creation. One can create templates for *Anki* that allow for the entry of words and information to be uniform. These templates make it easy to create unique flashcards, for instance cloze sections and reverse flashcards with just a click of a few buttons.

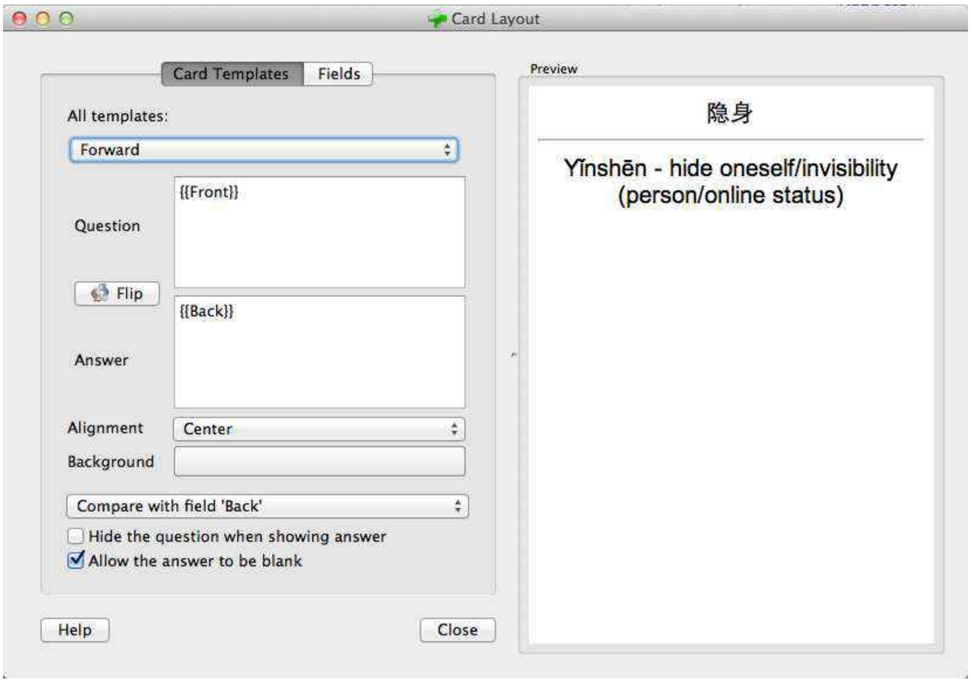


Figure 3: Example of template creation in Anki

Anki and *Mnemosyne* are both open-source programs and allow for the inclusion of third-party plugins. This is beneficial to the learner as improvements and fixes in the applications occur frequently.

3.1.2 Goals of the Applications

The spaced repetition applications developed for this research is to be tested with first year students who are learning Chinese as a foreign language. The exact details of these students and the materials used are explained in the implementation phase of the ADDIE process in the next chapter. However, certain goals and features were adhered to as a general guideline in the design and development of the applications:

- Only the features of spaced repetition systems that show flashcards and integrate the spacing effect are needed. Other features, such as card creation, complex long-term spacing algorithms and statistics are not needed for this study.
- The control application has to mimic a spaced repetition system as closely as possible without adding features or removing essential features from the study.
- The experimental application will display additional information related to Chinese orthography, specifically information about radicals, thus these design and development considerations are considered.
- The difference between the control and experimental application must be minimal, to invoke only the variable that will be tested in the implementation phase. Thus, there should be no design differences in terms of color scheme and general feeling of the applications.

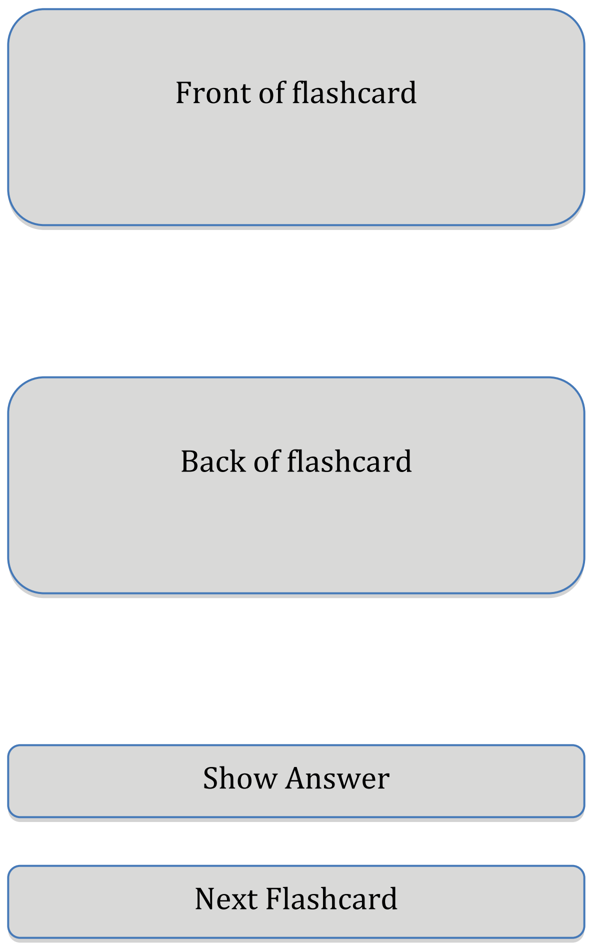
The materials that were used in both applications are discussed in the implementation phase. However, as was discussed in the literature review, the addition of Chinese radicals aids in character recognition, naming and recall. Furthermore, it is the most beneficial when displayed at the first introduction of a word (Taft & Chung, 1999). Thus, in developing the experimental version of the application, it was considered advantageous that the front of the flashcard display information on the character concerning its radical composition.

3.2 Design

After looking at the design of current implementations of spaced repetition systems and examination of the consistency between them, the design of the present study follows similar patterns used in *Anki* and *Mnemosyne*. A box at the top for the front of the flashcard and a box at the bottom for the back of the flashcard are used which is consistent with the design in *Anki* and *Mnemosyne*. An additional "show answer" button is placed underneath the bottom box. The self-grading buttons will be removed, as these do

not affect the current implementation of the study, as it is a short-term study. Instead a "next flashcard" button is placed right at the bottom.

A similar monochrome colour scheme to *Anki* and *Mnemosyne* is used, but a small splash of red has been added as this is one of China's national colours. Care is taken that characters are centered in the boxes and that the typeface is as clear as possible by using a 30pt font size on both the front and the back of the flashcard. The sizes of both boxes are also consistently uniform.



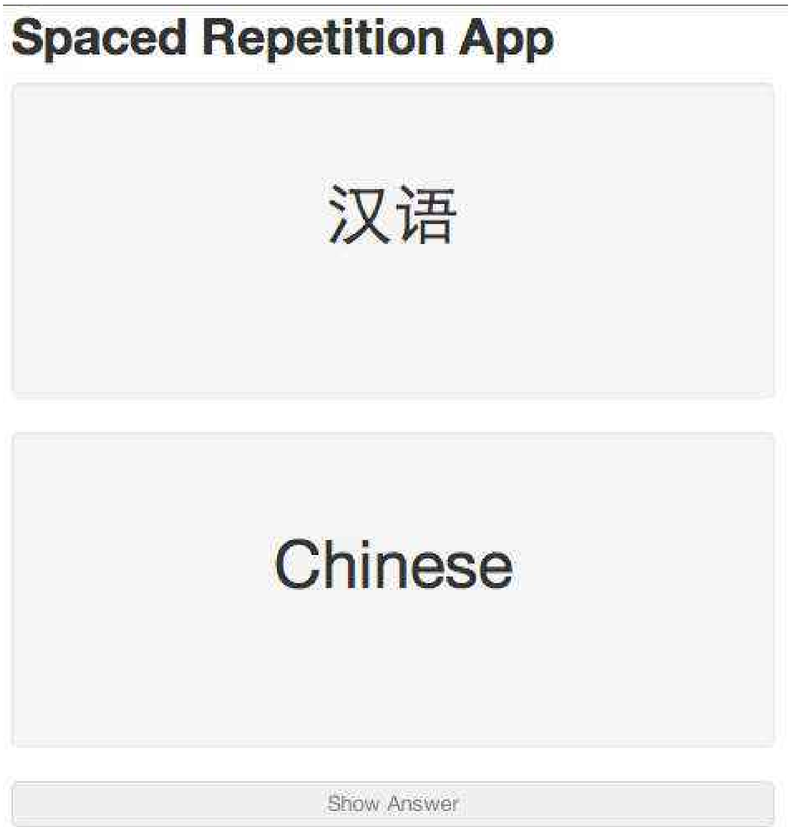


Figure4: Early version of Dragon SRS

At the bottom, in similar design to *Anki* and *Mnemosyne*, details at the bottom are shown that correspond to how many cards are in the deck and how many are left to review.

The application is to be called Dragon. This was chosen, because of the importance of dragons in Chinese culture and mythology.

3.3 Development

The researcher undertook the development of the control and experimental applications. While *Anki* and *Mnemosyne* are desktop applications, this researcher opted to develop an online version as this means that a prototype can be created to display in multiple browsers and on multiple platforms. The technologies that were used were HTML, CSS, jQuery, Javascript and Bootstrap which is hosted online by using Node.js and Heroku.

HTML allows for information to be shown in browsers. CSS is used to style and create the design elements of the application, for instance, the monochrome scheme and buttons. Bootstrap is a preset framework created by Twitter for rapid development of websites using pre-existing styles and CSS classes (Bootstrap, 2012). These styles are of a high caliber and add a professional aesthetic to the application. One can then easily extend these styles by adding one's own design touches. Furthermore, Bootstrap has a flexible grid structure built into the code that allows for easy placing of information within the browser window.

By using Javascript and jQuery, interactivity can be added, as well as creating arrays for the sequence of words and flashcards that are to be displayed in the application. Javascript and jQuery thus minimize the need for additional files, because one need not create extra HTML pages for each flashcard.

Bootstrap styling is built around pre-defined CSS classes, which help with the layout among, other design features. To use Bootstrap, one need only to download the CSS file and link it to the HTML documents. As an example of Bootstrap styles, for instance to get a Bootstrap style button, one only needs to add the *btn* class to a HTML button:

```
<button class=”btn”>Show Answer</button>
```

This would yield a button like this:

instead of the default styling for Google Chrome below.

The button class is then extended in an additional CSS file (see Addendum A) that adds extra design elements to the *btn* class, for instance adding a darker border to make it stand out more against a white background.

The flashcard boxes are created by using the Bootstrap *well* class, which gives the assigned *div* element a slightly darker background as well as curved corners. This creates a clear delineation of where the flashcard information resides which is similar to the style of *Anki* and *Mnemosyne*.

Once again, the *well* style has been extended to add red tinted border to the sides of the flashcard.

A similar procedure was followed to *Anki* and *Mnemosyne*. First, the top word will be displayed. This word corresponds to a pre-defined array that sits within an external Javascript file that handles the interactivity in the application. Then to reveal the back of the flashcard the *show answer* button must be pressed. jQuery picks up this action and triggers a Javascript function called *showFlashcard* (see Addendum B) which updates the lower box with the corresponding information. It also disables the *show answer* button by adding the class *disabled* to the button and activates the *next flashcard* button by removing the *disabled* class. This class was obtained from Bootstrap. When the next flashcard button is pressed, jQuery picks up the action again and the function *nextFlashcard* is triggered. Both boxes are cleared and the top one instantly reveals the front side of the next flashcard. The buttons are given the same treatment as before by toggling the *disabled* classes back to its original state. A variable, *progress*, keeps track of how many cards have been displayed. This is also shown at the bottom of the second box, which displays the details of the current deck of flashcards.

This procedure continues until all the flashcards have been shown. The learner will be able to see how many presentations are left by looking at the details at the bottom of the application. This is also updated with each trigger of the *nextFlashcard* function.

The files used in the program are hosted on Heroku using Node.js. Node.js is a programming language that allows the programmer to create a fully functional web server using Javascript. Using this open-source technology one can host the HTML, CSS and Javascript files on Heroku which a cloud-hosting service that enables small websites to be effectively hosted for free.

The current research experiment can be accessed by going to the url:
http://srs-experiment.herokuapp.com

3.4 Conclusion

Spaced repetition systems are flashcard applications that use the spacing effect and forgetting curve and are based on Wozniak's *SuperMemo* Algorithms. These systems are homogenous in design, with the front of the flashcard usually displayed at the top and the back of the flashcard displayed at the bottom.

There are various features that *Anki* and *Mnemosyne* have such as flashcard creation and statistics which are not built into the application used for the study, which will only test recall as influenced by two variables, namely the spacing effect and Chinese orthography. To reiterate, the application built for the experiment is a prototype that is only used to test variables as set out for the experiment. A control version will recreate the experience of spaced repetition systems as closely as possible in order to keep the spacing effect intact.

The application was built using HTML, CSS, Javascript, jQuery and Bootstrap. The styling and aesthetic relies heavily on Bootstrap, which adds a clean professional look to the application.

Chapter 4: Implementation & Evaluation

In this chapter the last two steps of the ADDIE model, implementation and evaluation, will be documented. The implementation phase will provide the methodology, choice of materials, research design and procedure as well as the hypothesis involved in the experiment. The section on evaluation (4.2) documents the results and includes a discussion on the findings of the experiment.

4.1 Implementation

In the design and development stages of the ADDIE model, a control version of the flashcard system, Dragon, was developed. It was based on an analysis of existing spaced repetition systems called *Anki* and *Mnemosyne*. In the implementation phase the experimental version will be documented further as well as the choice of materials and research design.

4.1.1 Materials

Choosing the Chinese characters applicable to the study was given careful consideration, because of the complexity of Chinese orthography which is reliant on a number of variables that influence the recall and processing of Chinese characters. Evidence was shown in the literature review that there are five variables that one has to consider: frequency, consistency, combinality, regularity and transparency.

A further consideration in choosing the materials for this study is whether the students are familiar with the Chinese characters. The students should not have learned the specific Chinese characters used in the flashcard program before, as this will obviously influence the recall results.

The process in finding the right materials was started by analyzing the textbooks used by students at Stellenbosch University. Second and third year textbooks were the primary source for the Chinese characters considered for the flashcard program. Analysis of the

second and third year textbooks gave a higher probability that students would not already have encountered the characters in their first year textbooks.

Because of the variables that can influence recall in Chinese characters, a homogenous set of characters had to be chosen to provide consistent results of the spacing effect and experimental application additions to the application. With an inconsistent set of materials, influence of the variables on recall cannot be measured accurately.

Chinese characters with a left-right structure with two radicals, one on the left and one on the right, were initially sourced. After that, only semantic-phonetic compounds were chosen as they both contain a semantic and a phonetic radical. This aids in studying the recall of meaning and pronunciation in the characters. The other left-right structure Chinese characters that were not semantic-phonetic compounds were either pictograms or compound ideograms. These were removed.

To elucidate: only semantic-phonetic compounds with the semantic radical on the left and phonetic radical on the right were chosen. The characters with reversed semantic phonetic combinations were removed as they might create confusion within the short time allocated to the study.

Once I had a set of semantic-phonetic characters with the semantic radical on the left and phonetic radical on the right one I could start looking at the variables mentioned in the literature review: frequency, consistency, combinality, regularity and transparency.

Characters, especially semantic-phonetic compounds, with higher frequency, good consistency, high combinality, clear regularity and transparency are ones thatare both recognized and processed easier. The materials for this study aimed to find characters that have relatively good scores on these variables as the influence of recall will then be determined by the other variables of the study and not necessarily the choice of hard to recall characters with low frequency, vague regularity and opaque meanings.

4.1.1.1 Analysis of Materials

Along with the second and third year textbooks, the first year textbook was analyzed by looking at the Chinese characters and their respective impacts on potential recall for the study. While the students would not have encountered all the Chinese characters in the first year textbook, an analysis of all the first year Chinese characters was done.

The students who participated in the experiment have been learning Chinese for just over one semester at Stellenbosch University which limits their exposure to Chinese characters. Therefore, one would surmise that effects such as consistency, combinality and frequency would have very limited effects on recall. For instance, frequencies of the characters were not counted in this analysis as the characters that were chosen for the study were based specifically on their unfamiliarity to the students which means that frequency has no effect on ability to recall items on the flashcards.

Considering the combinality of the phonetic radicals in semantic phonetic compounds, both the study materials and the characters from the first year textbook failed to show any significant phonetic radicals that might impact the recall. The numbers of exposure to differing Chinese characters is just too low for students at this level of study. There are more phonetic radicals that contribute to the formation of semantic-phonetic compounds thus this observation is normal.

The combinality of semantic radicals in semantic-phonetic compounds and compound ideograms were also examined. The decision to include compound ideograms in the semantic radical combinality analysis is because semantic radicals in compound ideograms attribute meaning in the same way that semantic radicals would in semantic-phonetic compounds.

Three radicals showed very high combinality with more than ten characters for each radical: 口 (mouth), 人 (person) and 言 (speech). Other radicals with high combinality are 手 (hand) and 辶 (walk). Characters chosen for the study from the second and third year textbooks also had similar combinality frequencies with 手 (hand), 言 (speech), 木 (tree), 人 (person) and 水 (water) having the highest combinalities. Even though the semantic

radical combinalities are similar, it is unlikely with the students' limited exposure to the Chinese characters that combinality will have an impact on recall.

The same can be said for consistency effects. The exposure to the amount of Chinese characters at this level of study for these students is too low. For instance, when one looks at phonetic radical combinality, the average phonetic radical combines with only 1.35 characters. It is also unlikely that students have internalized the impact of the consistencies without having had explicit instruction on their impact.

The effects of consistency, frequency and combinality are labeled as inter-character relationships, because their impact arises from the knowledge of other Chinese characters. The two effects, regularity and transparency, are intra-character effects, in that their impact is determined by the relationship between the radicals and the character itself. For these effects one need not look at the first year textbooks, but at the characters from second and third year textbooks that have been chosen for the study.

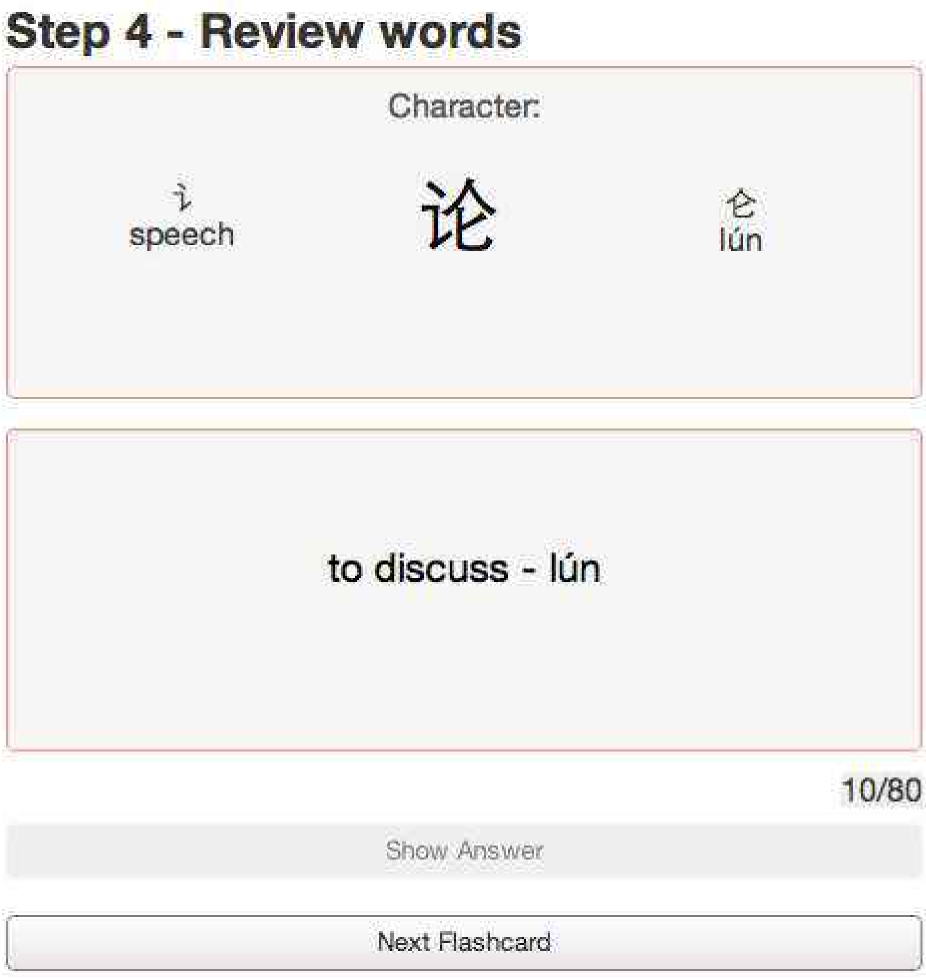
As mentioned earlier in this chapter left-right semantic-phonetic compounds were chosen. Further choices were determined by looking at the regularity and transparency of these characters. For the experiment a choice of regular and transparent characters were chosen to reduce inhibition of recall by hard to recall characters. This will ensure that recall of characters is potentially as effective as possible.

In order to maintain regularity, Chinese characters with phonetic radicals that have the same pronunciation or differing only on tone were chosen. From this set of regular characters, transparent characters were chosen. Only characters with a close and clear relationship in meaning between the character and semantic radical were selected. These characters comprised the final selection of fifty-two characters for the study (see Addendum C).

4.1.2 Experimental Application

As discussed in the chapter 3, two versions of the application was developed for the study: a control version and an experimental version. The experimental version tests the interaction between the spacing effect and the influence of additional information on

Chinese radicals in a flashcard system. The experimental version thus displays additional information on Chinese characters, specifically pertaining to the character's radical composition.



The additional information will be placed on the front of the flashcard (the top box). The semantic and phonetic radicals are displayed on the left and right respectively. Below these radicals additional information on them will also be displayed such as the meaning of the semantic radical and the pronunciation of the phonetic radical.

4.1.3 Research Design

The experiment tested the impact of the spacing effect and the addition of information of Chinese radicals on the recall of Chinese characters by using a flashcard system. Both the

spacing effect and Chinese radical instruction have separately been proven to improve recall (Lee *et al.*, 2005; Zhou & Marslen-Wilson, 1999; Hsiao *et al.*, 2007, Ebbinghaus, 1885; Baturay *et al.*, 2009; Bahrick *et al.*, 1993; Pavlik *et al.*, 2008; Bloom & Shuell, 1981; Kornell, 2009), however their interaction has not yet been tested. The experiment had a two by two design with a control group and experimental group. The between-subjects variable differed by presenting information on radicals or not. The within-subjects variable was the comparison between massed and spaced characters. We thus had four distinct combinations of the variables in the experiment: massed characters with no radical information, massed characters with radical information, spaced characters with no radical information and finally spaced characters with radical information.

The participants were chosen based on their limited exposure to Chinese characters. Thus only students who started studying Chinese in their first year were chosen. Because of the limited amount of students, the research design incorporated the massed and spaced word lists into one mixed list with spaced and massed characters together. Thus, in both versions of the application the students study the same list of characters. The only difference is that the experimental application will display additional information on radical. Students for the two groups were randomly selected.

The mixed list design uses fifty-two characters with each character repeated twice. The massed words have no intervening items whereas the spaced words have three intervening items. The mixed list design would thus be repeated in this pattern for words ABCD:

A, B, C, C, A, B, D, D

Four random characters were added to the front and back of the list to create primacy and recency buffers which prevent any memory bias that might occur to the first few and last few characters (Ebbinghaus, 1885; Murdock, 1962; Brooks, 1999). The primacy and recency buffers are not included in the test.

The following hypothesis was tested:

Students who learn Chinese characters where both the spacing effect and information on Chinese radicals are present in a flashcard system will have better recall. The converse is similarly true, that students who learn flashcards with massed characters with no information on radicals will perform worse in recall.

4.1.4 Procedure

Eighteen first year students of Chinese as a foreign language at the University of Stellenbosch were randomly divided into two groups. The students are then asked to access a webpage. Students from each group were given access to the website. Once on the site, which was created specifically for the experiment, the students select the option that corresponds to the group in which they were placed.

Group one used the control version and group two used the experimental version of the program. Selecting the appropriate option, a web page displays the instructions for the program and procedure of the experiment. After reading the instructions, students proceed to the next web page where a list of all the characters in the study are displayed along with the pronunciation and meaning of each. This list is presented one character at a time, for five seconds each, to restrict any bias occurring regarding how students implement their own strategies towards a list of characters, or a bias to distribution of attention to characters. Primary and recency buffers are also in this list to prevent a further bias to the first and last few characters.

After the students completed in the study of the characters, they proceed towards the flashcard application. Here they attempt to recall meaning and pronunciation of the Chinese character, before proceeding to the next character.

After review of all the characters, a distractor math problem is provided on screen, which further prevents any bias to recent characters. Once this as been completed the students indicate that they have finished. A test paper of all fifty-two characters is provided in which the students have to recall the meaning and pronunciation of the Chinese characters (see Addendum D).

Step 1	Access website and proceed to the group to which student was assigned.
Step 2	Read instructions on how the flashcard program works (group two had additional information on radicals)
Step 3	Study characters. Each character is presented for 5 sec each.
Step 4	Use flashcard application to review characters.
Step 5	Immediate post-test

Procedure for the experiment as broken down into five steps

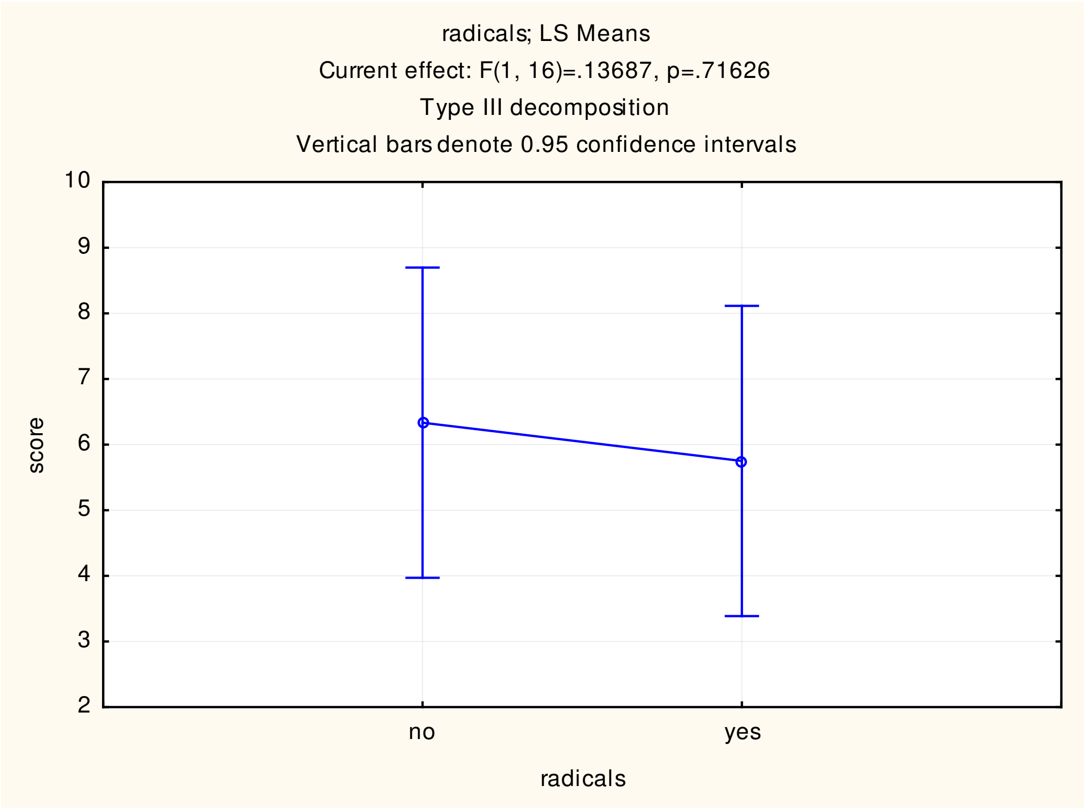
4.2 Evaluation

The results were determined by comparing the test scores of group one and two. Each character's correct meaning gets one point, while points for pinyin are awarded 0.5 for the correct syllable and another 0.5 if the tone is correct. Thus, each character can have a total of two points. The total score for each test is 104.

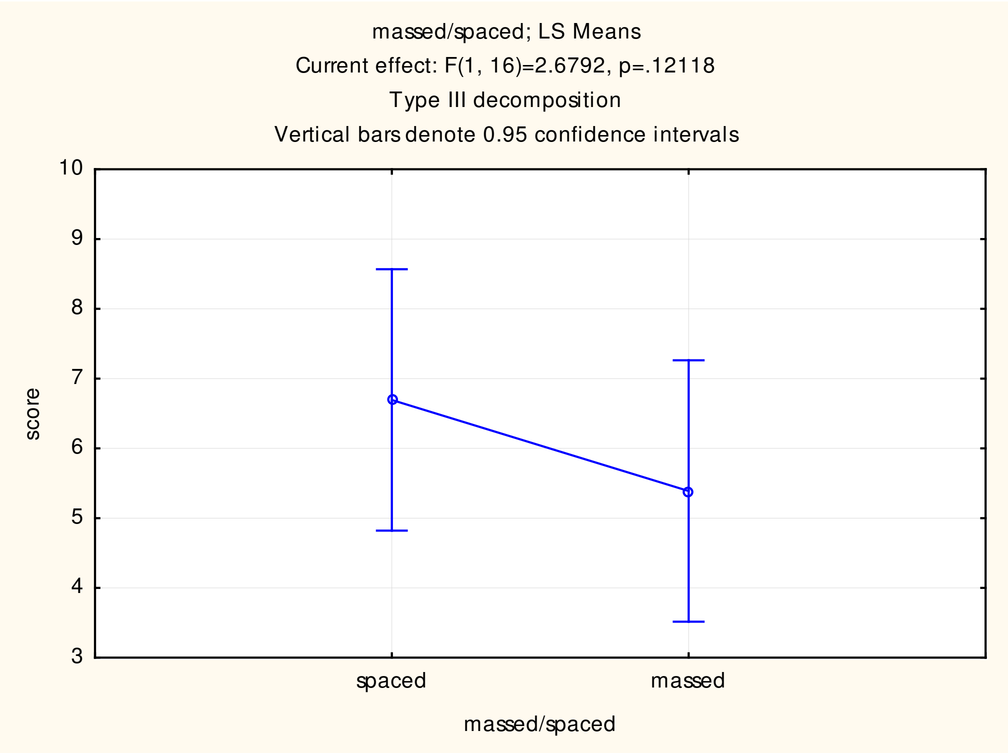
	Group1 (No Radicals)		
Student	Spaced	Massed	Total
1	2	0	2
2	2	2	4
3	4	7,5	7
4	6	4	10
5	6,5	4	10,5
6	13	1,5	14,5
7	11	8,5	19,5
8	10	10	20
9	9	13	22
AVG	7,06	5,61	12,17

	Group2 (Has Radicals)		
Student	Spaced	Massed	Total
1	1	2	3
2	4,5	3	7,5
3	5	3,5	8,5
4	5	3,5	8,5
5	5	5	10
6	5	5,5	10,5
7	7	6	13
8	10	8	18
9	14,5	10	24,5
AVG	6,33	5,17	11,5

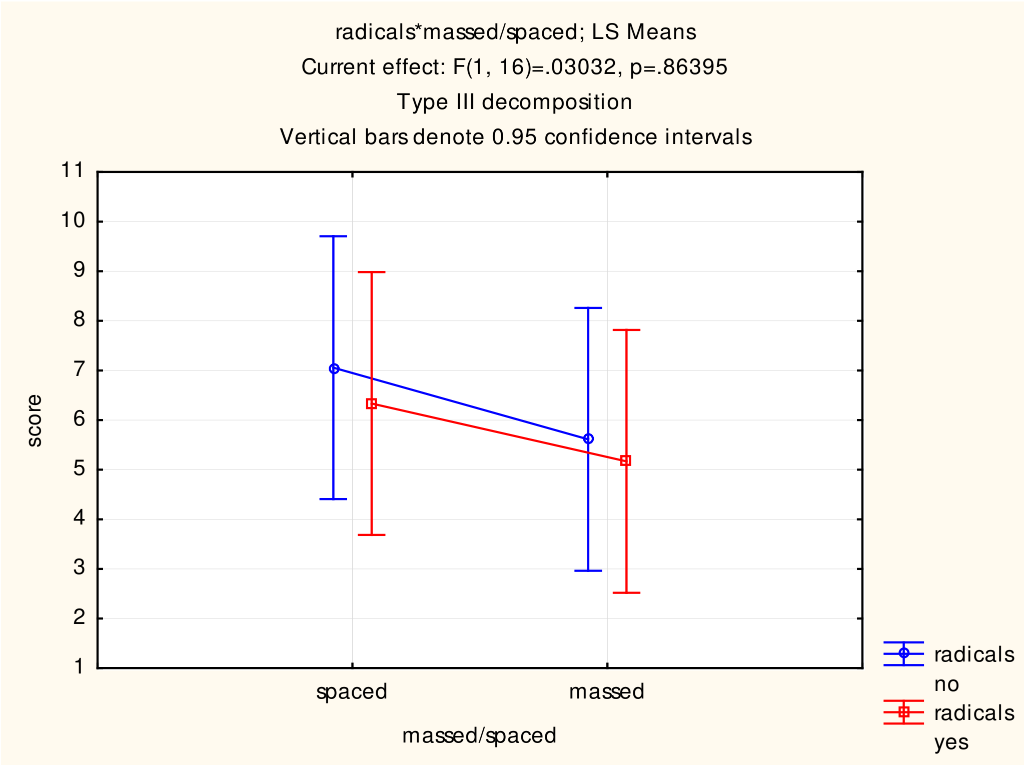
Both groups scored very low on the test. This was to be expected, as the students only had a short space of time to become familiar with the characters having been given only the study phase and two repetitions.



Assuming the null hypothesis, an unpaired T-test showed that there was no statistical difference between group one and group two's total scores ($p > 0.05$). In the mixed list design of spaced and massed characters, spaced characters were recalled better.



While the result is only just above statistical significance ($p = 0.12$) mainly due to the small sample size, one can detect a trend that confirms previous research done on the spacing effect as was evidenced in the literature review.



When one looks at the interaction between group one and group two and the spacing versus the massed effect, there is no significant statistical evidence of interaction between the variables. Thus, any variation of massed/spaced and radicals/no radicals and combinations of these variables do not seem to benefit one over the other.

4.2.1 Discussion

The hypothesis could not be supported by statistical evidence. Chinese characters that are spaced in an online flashcard system with additional information on their characters did not show the better recall results. The contrary to the hypothesis, that Chinese characters which are massed and have no additional information on their radical components did not show statistically significant worse performance.

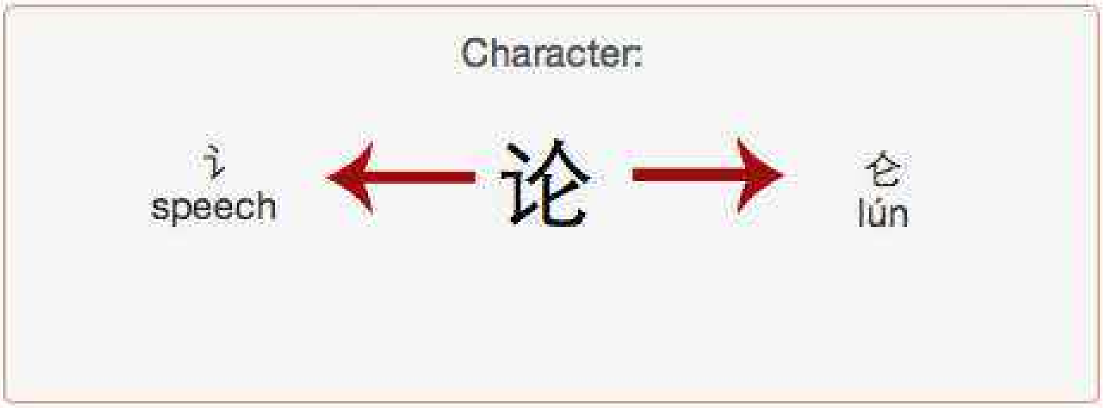
The effect of adding radical information on flashcards thus seems not to have a significant impact on the recall ability of the students. A base spacing effect was detected across both groups in which spaced characters had better recall than massed characters, however

there was no influence on the spacing effect depending on whether students had information on radicals or not. There can be various explanations for these results:

Although the radical information was provided to the students in group two and they were shown how this information fits into the character, students may not have inferred that radical information can contribute to better recall and processing of the Chinese character. Thus, the method of instruction on Chinese radicals could play a role in determining the impact of these radicals. In Taft & Chung's study (1999), the first time students saw characters, they were taught about the character's radicals and how they contribute to the meaning of the character. Explicit instruction could help students internalize these contributions better than presenting passive information on radicals. The possibility exists that students can internalize this information themselves, but for experimental purposes this cannot be tested without making sure that each student receives the same method of instruction.

Another explanation for the inconclusive result could be that the impact of additional information on radicals at such an early stage of character development could be nullified, when it comes to acquisition of meaning through the use of flashcards. As was mentioned in the previous paragraph, Taft & Chung (2009) showed that explaining radicals early in the exposure to the character was beneficial for the students, but with the use of flashcards, especially in an experimental design where recall focuses on the characters for short-term and not long-term recall benefits, students could have ignored the information on the radicals and only focused on establishing a quicker recall route to the character. This confirms a study done by Dunlap *et al.* (in press) that despite providing students with the option to use the additional information of radicals, they chose not to do so. Explicit instruction, however, helped students with long-term retention of the characters.

The design of the front flashcard for group two could also have impacted on the ability of the student to use the information of the additional radicals effectively. Perhaps a slow fade for the radicals could have drawn attention to their significance or an animation of the character's components. This would make the process less implicit.



Demonstration of potential design change that might influence the impact of the addition of information on Chinese radicals, which are animated movements of them away from the character to their current positions.

Demonstration of potential design change that might influence the impact of the addition of information on Chinese radicals, which are animated movements of them away from the character to their current positions.

One can even postulate that a flashcard should only have one unit of recall and that other information could potentially introduce confusion or have no effect at all. Perhaps additional flashcards presented before the main character, specifically marked as radical flashcards could focus the attention on radicals before the students look at the character which is composed of those radicals.

A closer analysis of the answers given by both groups one and two provides an interesting finding: students they did significantly better ($p < 0.05$) at scoring points for the correct meaning compared to points gained for the correct pinyin. When one looks at the connectionist models of lexical processing of Chinese characters (Seidenberg, 1985; Seidenberg & McClelland, 1989; Taft & Zhu, 1997), what occurred here might be explained by a similar finding by Yang *et al.* (2006) and Williams and Bever (2010), namely that students learn the connection of grapheme to meaning easier than the grapheme to sound relationship. One can also argue that because the pronunciation was not vital for a written test, students focused even more on establishing a grapheme-meaning relationship. There

may have been influence of the meaning radical to help with the meaning, but this was not tested.

One can, however, say that because the spacing effect that was found to have significant influence in both groups, the radicals played no role in determining recall. Further evidence for this was found in the fact that no variation of the spacing versus massed characters and flashcards with information on radicals and flashcards with no information, proved any better in recall against any other variation of these possible combinations.

Presenting radicals on a flashcard might not be the best way to implement the beneficial effects radicals have on recall. Helen & Ke (2007) found that there was a positive correlation between application knowledge of radicals and word acquisition in learners of Chinese as a foreign language. As these students did not have a solid foundation for radical knowledge application, this could explain why radicals might not have provided the beneficial effect that the hypothesis was looking for. Helen & Ke make a distinction between radical knowledge application and radical knowledge. According to these researchers, knowledge of radicals does not necessarily equate to applying that knowledge, specifically in word acquisition.

The current experiment only tested a small subset of Chinese characters: semantic-phonetic compounds that were semantically transparent and regular in pronunciation. Although previous research has shown that transparent and regular characters are better recalled and read more easily (Lee *et al.*, 2005; Zhou & Marslen-Wilson, 1999; Hsiao *et al.*, 2007), they showed no impact in the current experiment because all characters were in the same category. The influence of the transparent semantic radicals and regular phonetic radicals was meant to aid recall and not inhibit it. Even within this optimal situation for recall of Chinese characters, the presentation of information on Chinese radicals had no impact on these characters. The possibility that other types of characters might have a different impact on recall was not tested.

In summary, the initial hypothesis was not supported by statistical evidence. Adding information on radicals to flashcards does not seem to contribute to better recall. A trend

however was detected for the spacing effect, but this does not impact on the results between group one and two. There could be various explanations for these results: the method of instruction on the impact of radicals could play a role in how well the beneficial effect of the inclusion of information on radicals work. Another explanation could be that flashcards do not provide a good medium for the introduction of radicals, especially early in the learner's exposure to Chinese characters. The design could also be at fault, as too much information might have been confusing to the learner. A final interesting finding was that when students got answers correct, they scored more points for meaning, rather than pinyin. This confirms that Chinese characters act differently than other scripts, where the relationship between grapheme-to-meaning has precedence over grapheme-to-sound relationships.

4.3 Conclusion

In this chapter the two final steps of the ADDIE methodology were documented: implementation and evaluation. In the implementation stage careful consideration was given to the choice of materials for the experiment. The Chinese characters that were chosen were taken from the second- and third year textbooks of Chinese students at Stellenbosch University. The changes for the experimental application were described.

A research design was chosen in which one group used the control application and the other group the experimental application. The experimental application had additional information on the radicals that make up the construction of the character. Both groups study the same mixed list of spaced and massed characters. A hypothesis was put forward that students who learned spaced characters along with information on radicals would perform better in recall compared to students who had no information on radicals and were presented with massed characters. The contrary was also tested that students who learned massed characters with no information on the radicals would perform worse.

The hypothesis was not conclusively proven. There was no marked improvement when students had information on radicals. A trend emerged in which spaced characters outperformed massed characters. No advantage was found for spaced characters that had information on radicals. The massed characters with no information on radicals also did

not perform worse than any other category. Even with the small sample, this experiment can confirm that the presentation of radicals on flashcards will not significantly impact the ability of recall for the students.

Chapter 5: Conclusion

In this final chapter a summary of the thesis is given as well as a documentation of the possible impact of this research on Chinese language learning pedagogy and suggestions for further research opportunities.

5.1 Summary

This thesis set out to explore efficacious ways in which to learn Chinese vocabulary. One way would be to use spaced repetition systems in the form of digital flashcard applications that use verifiable cognitive effects such as the spacing effect, the forgetting curve and the testing effect to improve recall of vocabulary information on flashcards. Spaced repetition systems are especially beneficial for learning the substantial number of new vocabulary items necessary when setting out to learn a new language. The spacing effect has been shown to be a cognitive phenomenon in which the spacing of repetitions of vocabulary items improves students' ability to recall these items. The forgetting curve is an extension of the spacing effect that tries to determine the most efficient spacing of repetitions to just before the learner is about to forget a vocabulary item.

The spacing effect is a fundamental part of these spaced repetition systems. However, because spaced repetition systems make provision for all languages and general flashcard use, no specific implementation for Chinese was found by this researcher. Such a more specific implementation was deemed desirable because of the complex orthography of Chinese script that is completely different from alphabet-based languages. One such difference which could be experienced as problematic is the sheer number of Chinese characters that a student has to learn, a state which can be ameliorated by focusing on radicals.

Chinese radicals are sub-lexical units, also called components, which impact on reading, processing and recall of Chinese characters. There are various variables that can affect the systematization of Chinese characters for students: frequency of the character and radical, consistency of the information provided by the radicals, the regularity of pronunciation of

the phonetic radical versus the pronunciation of the character, semantic transparency of the semantic radical in relation to the meaning of the character and, finally, combinality which refers to the number of characters to which a radical can attach.

Connectionist models of processing orthography were used to explain these effects in this thesis. There are deeper activations among the radicals and the characters that they form with that can be accounted by a statistical modeling of these variables. When reading occurs, information is passed through the orthographic elements, namely the graphemes, which triggers other associations, such as pronunciation and meaning. In English the pronunciation is triggered while reading and is important in establishing a connection to the meaning of a word, but in Chinese, due to its structure as a logographic script, meaning plays a stronger role than pronunciation.

The acquisition of vocabulary is an integral part of learning a foreign language. Explicit instruction, such as the use of flashcards, is one method of learning vocabulary. For Chinese, knowledge of radicals has empirically been proved to enhance recall in cases where characters are transparent and regular, as well as have little interference from the variables consistency, frequency and combinality. Research on the effect of instruction of radicals has proved to be positive, in that it not only improves long-term memory but also increases orthographical knowledge. The latter is used to establish better procedures in order to learn new characters.

In the third chapter, the thesis looked at two widely used spaced repetition systems, *Anki* and *Mnemosyne*, and how they are designed. This formed part of the analysis phase of the ADDIE methodology. Using this analysis, a control version of a prototype spaced repetition system was designed and developed. The more complex algorithms were not implemented, as this study was intended as a short-term study. The spacing effect was still implemented using a mixed list design in which massed characters and spaced characters occur in the same list.

Javascript, HTML and CSS along with pre-built modules, jQuery and Bootstrap, that were used to add interactivity and elements of professional design, were used to develop the

application. It was then hosted online on a cloud-hosting service called Heroku using Node.js as a back-end server language.

In Chapter Four, further analyses are described regarding the choice of materials for the experiment. The experiment set out to test the interaction between the spacing effect and inclusion of information on radicals in a spaced repetition system. The hypothesis was put forward that students who studied characters which were spaced and had information on radicals would perform better on an immediate post-test than students whose flashcards were not structured in this way. A contrary to the above hypothesis, namely that those students whose flashcards contain massed characters with no information on radicals would perform worse.

The characters for the experiment were chosen from the second and third year textbooks of students of Chinese as a foreign language at Stellenbosch University. This ensured that students would not have encountered the characters used for the experiment before. In the end fifty-two characters were identified for inclusion in this study. They were semantic-phonetic compounds with clear left-right structures, transparent semantic radicals and regular phonetic radicals. This ensured that no interference occurred when students tried to recall characters.

For the experiment students were separated into two groups, one that had information on radicals on the front flashcard, while the other group did not. Before they could use their respective flashcard applications they were shown the list of fifty-two characters one by one for five seconds each. After using the application a test was given where students had to recall the meaning of the character and its pronunciation in pinyin.

None of the students performed very well on the test, and the hypothesis was, therefore, rejected based on this outcome as there was no difference in the results of the two groups. A positive correlation for the spacing effect itself was established, but the spacing effect had no statistically significant effect on whether the student had information on radicals or not. Thus, the hypothesis that flashcards with characters that are spaced and have information on radicals would lead to better performance was invalidated.

The result was surprising since there are positive research results that support the positive impact of information of radicals on the recall and processing of Chinese script. Several reasons for the result in this study were suggested. It does seem that the method of classroom instruction on radicals plays a bigger role than was expected, as students did not utilize the additional information provided on the flashcards. Moreover, flashcards are possibly not the best method to provide this type of instruction, because students may simply ignore the additional information, as they were not required to recall the meaning of radicals, but that of the entire character and its pronunciation. Having had no explanation regarding the positive impact that paying attention to the information on radicals could play in the dissemination of the meaning of characters, students most likely just disregarded the information. Therefore, the information on the radicals might have been superfluous in this instance.

Another result worth mentioning is that in instances where students scored points in the post-test, they scored significantly more for the correct meaning than for the correct pinyin. This confirms that Chinese has a stronger grapheme-to-meaning relationship than a grapheme-to-sound relationship. Although the information given to students on radicals did not have an impact on improved recall, the validity of the explanatory power of connectionist models for reading Chinese characters remains unchanged, because the findings of the current thesis suggests emphasis on the possible manner in which instruction on radicals affects recall, rather than the fact that radicals are indeed part of the processing of Chinese characters.

5.2 Impact on learning Chinese as a foreign language

Chinese characters are a big stumbling block for learners of Chinese as a foreign language. The current thesis set out to examine spaced repetition systems and whether information on radicals could improve recall of Chinese characters for beginner learners of Chinese. This research project established that there are variables that positively impact on the recall of Chinese characters. The experiment tested how transparent and regular semantic-phonetic compounds, which are readily recalled and processed, are affected, by

providing information on the radicals present in these compounds in a spaced repetition system.

The results showed that the passive introduction of information on radicals is not effective. Flashcards, although effective for deliberate learning of vocabulary items, especially combined with the spacing effect, may not be suited as a teaching tool on radicals. However, the inclusion of information on radicals can be beneficial if the teacher explicitly instructs the students on the benefits of knowledge of radicals, specifically in clarifying the meaning of characters and their manifestation in other characters. This facilitates a deeper understanding of Chinese orthography, which contributes to the ability of students to analyze new characters and develop radical application knowledge. If the learner is to utilize the information on Chinese radicals, then a conscious effort must be made to add radicals to their existing framework of knowledge of Chinese character, and also on how these radicals form part of the system of characters that is being acquired.

The current thesis only looked at a subset of Chinese characters, namely semantic-phonetic compounds with a clear left-right structure. Ideograms could also benefit from instruction on radicals, as they are composed of two semantic radicals.

Spaced repetition systems can undoubtedly augment the endeavors of any language learner, but the impact of information on Chinese radicals to improve recall in a flashcard-like system will have to be given a different treatment than what was set out in the current experiment. Teachers and learners thus need to be attentive when extra information is provided as the effect of this information is in how well that information is utilized and not merely its presence.

5.3 Impact on Spaced Repetition Systems

The current thesis confirms that the spacing effect facilitates learning Chinese characters. Students recalled spaced characters with better results than massed characters. However, when one looks at the original question that thesis set out to answer, i.e. whether a unique spaced repetition system with additional information on Chinese radicals improve the

recall ability of learners of Chinese as a foreign language, one has to conclude that this is still unresolved.

Flashcards may just not be suitable for the addition of extra information in the manner set out in the experiment. As mentioned in the discussion of the results, this finding is tentative, because the method of instruction and the absence of radical application knowledge of the learners might be the cause of these results. Further research needs to be conducted to deliver a conclusive finding on this issue.

5.4 Future Research

There are various reasons that could account for the lack of improvement that the inclusion of information on radicals evidenced in this study. One of the reasons could be the method of instruction. Students who are not aware of the impact of Chinese radicals might not utilize information given in an ad hoc manner effectively; therefore, research on whether explicit instruction has an effect on learners' own abilities to infer the significance of radicals on the semantic meaning of Chinese characters could be worthwhile.

The effect of explicit instruction could also be tested. In an experimental setting, one group of students could be given information on radicals and the way in which radicals improves understanding of the character. A control group would similarly receive semantic explanations on the same characters, but given no information on the radicals. These two groups would then use a flashcard system to determine their ability to recall Chinese characters. Essentially the same experiment that this thesis employed could be used which would then test whether the students who received explicit instruction utilize the additional information on the flashcards to their benefit or not. If the students do utilize the additional information after they have received explicit instruction, one can confirm that the effect of the addition of information on radicals in a flashcard system is truly beneficial.

On the subject of the spacing effect and its interaction with Chinese orthography, the current study did not confirm that it had any beneficial effect. However, this might be

because the radicals did not have the impact that they hypothetically could have had, because of the role played by explicit instruction. Once a study confirms that one group definitely has an advantage because of the inclusion of information on radicals, then the spacing effect and its interaction with this additional information can be tested.

Although the spacing effect is an integral part of spaced repetition systems, other cognitive effects, such as the testing effect and the forgetting curve are similarly fundamental to these systems. Future research could look at how these elements interact with Chinese orthography as well, especially aiming for long-term studies.

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Addendum A: Stylesheet for Application

```
/*----General-----*/


body{
	background-color: white;
	font-size: 16px;
}
h1{
	margin-bottom: 10px;
}

p{
	font-size: 1em;
}

#details{
	margin-top: -5px;
	margin-bottom: 8px;
	float: right;
	font-size: 12pt;
	background-color: #eee;
}

.flashcard{
	position: relative;
	height: 150px;
}

.btn{
	width: 100%;
	border: 1px solid #9b7b7a;
}

.disabled{
	border: 1px solid #eee;
}

.well{
	padding: 5px;
	margin-bottom: 15px;
	border: 1px solid #F08D8D;
}

#displayfield{
	font-size: 28pt;
	height: 250px;
```

```
        margin-top: 150px;
        padding-top: 25px;
        padding-bottom: 25px;
}

img{
        padding: 10px;
        border: 1px solid #eee;
        margin: 10px;
        margin-bottom: 0px;
}

.caption{
        padding: 10px;
        font-style: italic;
        font-size: 10pt;
}

/*----Control-----*/

#chardesc{
        width: 100px;
        margin: 5px auto;
        color: #555;
        font-size: 12pt;
}

#character{
        padding-top: 15px;
        padding-bottom: 25px;
        margin: 0 auto;
        color: black;
        font-size: 30pt;
}

#character2{
        padding-top: 15px;
        padding-bottom: 25px;
        margin: 0 auto;
        margin-right: 120px;
        color: black;
        font-size: 30pt;
}

#meaning{
        padding-top: 55px;
        padding-bottom: 15px;
        color: black;
        font-size: 15pt;
```

```
}

/*----Experimental----*/

#leftradical{
     width: 65px;
     float: left;
     margin-left: 50px;
     margin-top: 5px;
     font-size: 12pt;

}

#rightradical{
     width: 40px;
     float: right;
     margin-top: -50px;
     margin-right: 65px;
     font-size: 12pt;

}
```

Addendum B: Javascript files for control group and experimental group

Addendum B1 – Control Application

```
var progress = 0;
var words = new Array();

words.character = function(i){
return this[i][0];
}
words.semanticradical = function(i){
return this[i][1];
}
words.phoneticradical = function(i){
return this[i][2];
}
words.english = function(i){
return this[i][3];
}
words.pinyin = function(i){
return this[i][4];
}
words.radmeaning = function(i){
return this[i][5];
}
words.radpronunciation = function(i){
return this[i][6];
}
words[0] = ["搬", "扌", "般", "to move", "bān", "hand", "bān"];
words[1] = ["城", "土", "成", "city", "chéng", "earth", "chéng"];
words[2] = ["拒", "扌", "巨", "to resist", "jù", "hand", "jù"];
words[3] = ["懂", "忄", "董", "to understand", "dǒng", "heart",
"dǒng"];
words[4] = ["枫", "木", "风", "maple", "fēng", "tree", "fēng"];
words[5] = ["糕", "米", "羔", "cake", "gāo", "rice", "gāo"];
words[6] = ["湖", "氵", "胡", "lake", "hú", "water", "hú"];
words[7] = ["树", "木", "尌", "tree", "shù", "tree", "shù"];
words[8] = ["惜", "忄", "昔", "pity", "xī", "heart", "xī"];
words[9] = ["像", "亻", "象", "to resemble", "xiàng", "person",
"xiàng"];

words[10] = ["泳", "氵", "永", "to swim", "yǒng", "water",
"yǒng"];
```

```
words[11] = ["址", "土", "止", "location", "zhǐ", "earth",
"zhǐ"];
words[12] = ["把", "扌", "巴", "handle", "bǎ", "hand", "bā"];
words[13] = ["病", "疒", "丙", "illness", "bìng", "sickness",
"bǐng"];
words[14] = ["唱", "口", "昌", "to sing", "chàng", "mouth",
"chāng"];
words[15] = ["倒", "亻", "到", "to fall", "dǎo", "person",
"dào"];
words[16] = ["记", "讠", "己", "to remember", "jì", "speech",
"jǐ"];
words[17] = ["种", "禾", "中", "to plant", "zhòng", "grain",
"zhōng"];
words[18] = ["住", "亻", "主", "to live", "zhù", "person",
"zhǔ"];
words[19] = ["转", "车", "专", "to shift", "zhuǎn", "car",
"zhuān"];
words[20] = ["论", "讠", "仑", "to discuss", "lún", "speech",
"lún"];
words[21] = ["惊", "忄", "京", "to be frightened", "jīng",
"heart", "jīng"];
words[22] = ["游", "氵", "斿", "to swim", "yóu", "water", "yóu"];
words[23] = ["躲", "身", "朵", "to hide", "duǒ", "body", "duǒ"];
words[24] = ["疯", "疒", "风", "insane", "fēng", "sickness",
"fēng"];
words[25] = ["健", "亻", "建", "healthy", "jiàn", "person",
"jiàn"];
words[26] = ["婚", "女", "昏", "to marry", "hūn", "woman",
"hūn"];
words[27] = ["伸", "亻", "申", "to stretch", "shēn", "person",
"shēn"];
words[28] = ["按", "扌", "安", "to press", "àn", "hand", "ān"];
words[29] = ["摸", "扌", "莫", "to touch", "mō", "hand", "mò"];
words[30] = ["响", "口", "向", "echo", "xiǎng", "mouth",
"xiàng"];
words[31] = ["粽", "米", "宗", "rice dumpling wrapped in leaves",
"zòng", "rice", "zōng"];

//Recency + Primacy Buffers

words[-4] = ['裙','衣','君', 'skirt', 'tiáo', 'clothes', 'jūn'];
words[-3] = ['租','禾','且', 'to rent', 'zū', 'grain', 'qiě'];
words[-2] = ['嘴','口','觜', 'mouth', 'zuǐ', 'mouth', 'zuǐ'];
words[-1] = ['代','人','弋', 'to substitute','dài', 'person',
'yì'];
```

```
words[32] = ['活','氵','舌', 'to live','huó', 'water', 'shé'];
words[33] = ['泼','氵','发', 'to splash', 'pō', 'water',  'fā'];
words[34] = ['据','扌','居', 'according to', 'jù', 'hand', 'jū'];
words[35] = ['怪','忄','圣', 'strange', 'guài', 'heart',
'shèng'];

var linkarray = [-4,-3,-2,-2,-4,-3,-1,-
1,29,9,20,20,29,9,13,13,19,21,16,16,19,21,2,2,7,25,11,11,7,25,14
,14,23,15,3,3,23,15,6,6,24,22,0,0,24,22,12,12,5,28,1,1,5,28,18,1
8,30,27,17,17,30,27,10,10,26,31,8,8,26,31,4,4,32,33,34,34,32,33,
35,35];

$(document).ready(function(){
//Start App
$("#character").html(words.character(linkarray[progress]));
$("#details").html(progress + "/" + linkarray.length);

//Triggers
$("#showAnswer").click(function(){
showAnswer();
});

$("#nextFlashcard").click(function(){
nextFlashcard();
});
})

function showAnswer(){
$("#meaning").html(words.english(linkarray[progress]) + " - " +
words.pinyin(linkarray[progress]));
$("#showAnswer").addClass('disabled');
$("#nextFlashcard").removeClass('disabled');
}

function nextFlashcard(){
if(progress +1 < linkarray.length){
if($("#showAnswer").hasClass('disabled')){
progress = ++progress;
$("#details").html(progress + "/" + linkarray.length);
$("#front").css('display', 'none');
$("#character").html(words.character(linkarray[progress]));
$("#front").fadeIn('slow');
reset();
}
}
else{
$(".container").html("<h3>Well done!</h3><p>You have completed
the experiment. Please click the next button where you'll have
```

```
to do a few simplicistic math problems before you complete the
test.</p><br><button
onclick='window.location.href="+'"math.html"'+"'
class='btn'>Next</button>");
}
}

function reset(){
$("#meaning").html("");
$("#nextFlashcard").addClass('disabled');
$("#showAnswer").removeClass('disabled');
}
```

Addendum B2 – Experimental Application

```
var progress = 0;
var words = new Array();

words.character = function(i){
      return this[i][0];
}
words.semanticradical = function(i){
      return this[i][1];
}
words.phoneticradical = function(i){
      return this[i][2];
}
words.english = function(i){
      return this[i][3];
}
words.pinyin = function(i){
      return this[i][4];
}
words.radmeaning = function(i){
      return this[i][5];
}
words.radpronunciation = function(i){
      return this[i][6];
}
words[0] = ["搬", "扌", "般", "to move", "bān", "hand", "bān"];
words[1] = ["城", "土", "成", "city", "chéng", "earth", "chéng"];
words[2] = ["拒", "扌", "巨", "to resist", "jù", "hand", "jù"];
words[3] = ["懂", "忄", "董", "to understand", "dǒng", "heart",
"dǒng"];
words[4] = ["枫", "木", "风", "maple", "fēng", "tree", "fēng"];
words[5] = ["糕", "米", "羔", "cake", "gāo", "rice", "gāo"];
words[6] = ["湖", "氵", "胡", "lake", "hú", "water", "hú"];
words[7] = ["树", "木", "尌", "tree", "shù", "tree", "shù"];
words[8] = ["惜", "忄", "昔", "pity", "xī", "heart", "xī"];
words[9] = ["像", "亻", "象", "to resemble", "xiàng", "person",
"xiàng"];
words[10] = ["泳", "氵", "永", "to swim", "yǒng", "water",
"yǒng"];
words[11] = ["址", "土", "止", "location", "zhǐ", "earth",
"zhǐ"];
words[12] = ["把", "扌", "巴", "handle", "bǎ", "hand", "bā"];
words[13] = ["病", "疒", "丙", "illness", "bìng", "sickness",
"bǐng"];
```

```
words[14] = ["唱", "口", "昌", "to sing", "chàng", "mouth",
"chāng"];
words[15] = ["倒", "亻", "到", "to fall", "dǎo", "person",
"dào"];
words[16] = ["记", "讠", "己", "to remember", "jì", "speech",
"jǐ"];
words[17] = ["种", "禾", "中", "to plant", "zhòng", "grain",
"zhōng"];
words[18] = ["住", "亻", "主", "to live", "zhù", "person",
"zhǔ"];
words[19] = ["转", "车", "专", "to shift", "zhuǎn", "car",
"zhuān"];
words[20] = ["论", "讠", "仑", "to discuss", "lún", "speech",
"lún"];
words[21] = ["惊", "忄", "京", "to be frightened", "jīng",
"heart", "jīng"];
words[22] = ["游", "氵", "斿", "to swim", "yóu", "water", "yóu"];
words[23] = ["躲", "身", "朵", "to hide", "duǒ", "body", "duǒ"];
words[24] = ["疯", "疒", "风", "insane", "fēng", "sickness",
"fēng"];
words[25] = ["健", "亻", "建", "healthy", "jiàn", "person",
"jiàn"];
words[26] = ["婚", "女", "昏", "to marry", "hūn", "woman",
"hūn"];
words[27] = ["伸", "亻", "申", "to stretch", "shēn", "person",
"shēn"];
words[28] = ["按", "扌", "安", "to press", "àn", "hand", "ān"];
words[29] = ["摸", "扌", "莫", "to touch", "mō", "hand", "mò"];
words[30] = ["响", "口", "向", "echo", "xiǎng", "mouth",
"xiàng"];
words[31] = ["粽", "米", "宗", "rice dumpling wrapped in leaves",
"zòng", "rice", "zōng"];

//Recency + Primacy Buffers

words[-4] = ['裙','衣','君', 'skirt', 'tiáo', 'clothes', 'jūn'];
words[-3] = ['租','禾','且', 'to rent', 'zū', 'grain', 'qiě'];
words[-2] = ['嘴','口','觜', 'mouth', 'zuǐ', 'mouth', 'zuǐ'];
words[-1] = ['代','人','弋', 'to substitute','dài', 'person',
'yì'];

words[32] = ['活','氵','舌', 'to live','huó', 'water', 'shé'];
words[33] = ['泼','氵','发', 'to splash', 'pō', 'water',  'fā'];
words[34] = ['据','扌','居', 'according to', 'jù', 'hand', 'jū'];
```

```
words[35] = ['怪','忄','圣', 'strange', 'guài', 'heart',
'shèng'];

var linkarray = [-4,-3,-2,-2,-4,-3,-1,-
1,29,9,20,20,29,9,13,13,19,21,16,16,19,21,2,2,7,25,11,11,7,25,14
,14,23,15,3,3,23,15,6,6,24,22,0,0,24,22,12,12,5,28,1,1,5,28,18,1
8,30,27,17,17,30,27,10,10,26,31,8,8,26,31,4,4,32,33,34,34,32,33,
35,35];

$(document).ready(function(){
	//Start App
	$("#character2").html(words.character(linkarray[progress]))
;
	$("#leftradical").html(words.semanticradical(linkarray[prog
ress]) + "<br>" + words.radmeaning(linkarray[progress]));
	$("#rightradical").html(words.phoneticradical(linkarray[pro
gress]) + "<br>" + words.radpronunciation(linkarray[progress]));
	$("#details").html(progress + "/" + linkarray.length);

	//Triggers
	$("#showAnswer").click(function(){
		showAnswer();
	});

	$("#nextFlashcard").click(function(){
		nextFlashcard();
	});
})

function showAnswer(){
	$("#meaning").html(words.english(linkarray[progress]) + " -
" + words.pinyin(linkarray[progress]));
	$("#showAnswer").addClass('disabled');
	$("#nextFlashcard").removeClass('disabled');
}

function nextFlashcard(){
	if(progress+1 < linkarray.length){
		if($("#showAnswer").hasClass('disabled')){
			progress = ++progress;
			$("#details").html(progress + "/" +
linkarray.length);
			$("#front").css('display', 'none');

	$("#character2").html(words.character(linkarray[progress]))
;

	$("#leftradical").html(words.semanticradical(linkarray[prog
ress]) + "<br>" + words.radmeaning(linkarray[progress]));
```

```
	$("#rightradical").html(words.phoneticradical(linkarray[pro
gress]) + "<br>" + words.radpronunciation(linkarray[progress]));
			$("#front").fadeIn('slow');
			reset();
		}
	}
	else{
		$(".container").html("<h3>Well done!</h3><p>You have
completed the experiment. Please click the next button where
you'll have to do a few simplicistic math problems before you
complete the test.</p><br><button
onclick='window.location.href="+'"math.html"'+"'
class='btn'>Next</button>");
	}
}

function reset(){
	$("#meaning").html("");
	$("#nextFlashcard").addClass('disabled');
	$("#showAnswer").removeClass('disabled');
}
```

Addendum C: List of characters for study

1) 搬	14) 惜	27) 注	40) 伙
2) 城	15) 像	28) 转	41) 挣
3) 诚	16) 议	29) 论	42) 按
4) 懂	17) 泳	30) 惊	43) 搭
5) 枫	18) 址	31) 游	44) 档
6) 糕	19) 把	32) 躲	45) 根
7) 湖	20) 病	33) 疯	46) 姑
8) 境	21) 唱	34) 健	47) 拢
9) 楼	22) 倒	35) 婚	48) 瑰
10) 奶	23) 傅	36) 拒	49) 摸
11) 树	24) 记	37) 漫	50) 晌
12) 味	25) 种	38) 伸	51) 饼
13) 温	26) 住	39) 征	52) 粽

Addendum D: Test

Student Nr: ______________

Please fill in the Pinyin and the meaning of the character to the best of your ability. If you can't remember, it is okay to leave the answer fields blank, but guess your best answer first.

1) 搬

Meaning: _____________ Pinyin: _________________

2) 城

Meaning: _____________ Pinyin: _________________

3) 诚

Meaning: _____________ Pinyin: _________________

4) 懂

Meaning: _____________ Pinyin: _________________

5) 枫

Meaning: _____________ Pinyin: _________________

6) 糕

Meaning: _____________ Pinyin: _________________

7) 湖

Meaning: _____________ Pinyin: _________________

8) 境

Meaning: _____________ Pinyin: _________________

9) 楼

Meaning: ____________ Pinyin: ________________

10) 奶

Meaning: ____________ Pinyin: ________________

11) 树

Meaning: ____________ Pinyin: ________________

12) 味

Meaning: ____________ Pinyin: ________________

13) 温

Meaning: ____________ Pinyin: ________________

14) 惜

Meaning: ____________ Pinyin: ________________

15) 像

Meaning: ____________ Pinyin: ________________

16) 议

Meaning: ____________ Pinyin: ________________

17) 泳

Meaning: ____________ Pinyin: ________________

18) 址

Meaning: ____________ Pinyin: ________________

19) 把

Meaning: ____________ Pinyin: ________________

20) 病

Meaning: ____________ Pinyin: ________________

21) 唱

Meaning: ____________ Pinyin: ________________

22) 倒

Meaning: ____________ Pinyin: ________________

23) 傅

Meaning: ____________ Pinyin: ________________

24) 记

Meaning: ____________ Pinyin: ________________

25) 种

Meaning: ____________ Pinyin: ________________

26) 住

Meaning: ____________ Pinyin: ________________

27) 注

Meaning: ____________ Pinyin: ________________

28) 转

Meaning: ____________ Pinyin: ________________

29) 论

Meaning: ____________ Pinyin: ________________

30) 惊

Meaning: ____________ Pinyin: ________________

31) 游

Meaning: ____________ Pinyin: ________________

32) 躲

Meaning: ____________ Pinyin: ________________

33) 疯

Meaning: ____________ Pinyin: ________________

34) 健

Meaning: ____________ Pinyin: ________________

35) 婚

Meaning: ____________ Pinyin: ________________

36) 拒

Meaning: ____________ Pinyin: ________________

37) 漫

Meaning: ____________ Pinyin: ________________

38) 伸

Meaning: ____________ Pinyin: ________________

39) 征

Meaning: ____________ Pinyin: ________________

40) 伙

Meaning: ____________ Pinyin: ________________

41) 挣

Meaning: ____________ Pinyin: ________________

42) 按

Meaning: ____________ Pinyin: ________________

43) 搭

Meaning: ____________ Pinyin: ________________

44) 档

Meaning: ____________ Pinyin: ________________

45) 根

Meaning: ____________ Pinyin: ________________

46) 姑

Meaning: ____________ Pinyin: ________________

47) 拢

Meaning: ____________ Pinyin: ________________

48) 瑰

Meaning: ____________ Pinyin: ________________

49) 摸

Meaning: ____________ Pinyin: ________________

50) 响

Meaning: ____________ Pinyin: ________________

51) 饼

Meaning: ____________ Pinyin: ________________

52) 粽

Meaning: ____________ Pinyin: ________________