Possible Effects of English-Chinese Language Differences on the Processing of Mathematical Text: A Review

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When comparing Chinese and English language, large differences in orthography, syntax, semantics, and phonetics are found. These differences may have consequences in the processing of mathematical text, yet little consideration is given to them when the mathematical abilities of students from these different cultures are compared. This paper reviews the differences between English and Mandarin Chinese language, evaluates current research, discusses the possible consequences for processing mathematical text in both languages, and outlines future research possibilities.

At all levels of education and in any language, students need to process mathematical text. For example, the statement *A line is 2 cm longer than a match* requires a certain amount of processing. In Chinese, this statement reads 一条线比一根火柴长2公分 (*Yī tiáo xiàn bī yī gēn huǒchái cháng 2 gōngfēn*). Literally translated, the Chinese statement means *Line compare match long 2 cm*. In comparing the two sentences, not only is the visual text (i.e., the orthography) and the grammatical structure (i.e., the syntax) obviously different, but the word and phrase meaning (i.e., the semantics) and, when spoken, the speech structure (i.e., the phonology) also have many different characteristics. Do these differences have any impact on the way students process mathematical text?

This paper will outline the differences between Mandarin Chinese and English written languages in terms of syntax, orthography, phonology, and semantics and argue that all four linguistic features influence the processing of mathematical text. It will also discuss the literature on the influence of language on cognitive processing in general and on the processing of English and Chinese mathematical text in particular. Finally, it will provide a list of research questions based on the review outlined.

Language in Mathematics Learning

When students encounter a mathematical word problem, they need to read and understand the sentences and solve the problem. In the reading and understanding process, language is pivotal. There is a complex interaction between the words, the syntax, and the phonology, and this interaction helps to build up an image of the problem which may provide access to the appropriate solution schema.

From extensive mathematics education literature (e.g., Durkin & Shire, 1991; Ellerton & Clements, 1991, 1996), a set of characteristics of the English language can be identified as having a negative effect on students' performance in

mathematics, particularly the processing of mathematical text. However, do the linguistic attributes of another language have a different effect on student performance in mathematics? To answer this question, researchers in mathematics education have drawn from the literature on bilingual education, psycholinguistics, and sociolinguistics (Clarkson, 1991; Dawe, 1983b; Harris, 1980; Jones, 1982; Lean, 1992; Lean, Clements, & Del Campo, 1990). However, there have been relatively few cross-cultural studies of language and cognition in relation to mathematics (Cai, 1995, 1998; Fuson & Kwon, 1991; Stigler, Lee, Lucker, & Stevenson, 1982).

There is ample evidence in the linguistics literature suggesting that linguistic attributes can affect cognitive processing in general (Aaronson & Ferres, 1986). Some linguistic attributes of a language may allow for a lower cognitive load and hence more efficient processing than in English, but cross-linguistic comparisons have produced little evidence of cognitive advantage or disadvantage. The effect of language attributes on cognitive processing in different languages has been the subject of much debate since the 1930s, carried on by writers such as Sapir and Whorf (Whorf, 1956). A controversial hypothesis developed from this debate, the strong form of which states that thought is conditioned by language and that different languages may classify experience in different ways.

There has been much debate and research on the importance of learning and doing mathematics in a student's native tongue, rather than in a second language such as English (Harris, 1980; Nathan, Trinick, Tobin, & Barton, 1993; Spanos, Rhodes, Dale, & Crandall, 1988; Zepp, 1989). While most researchers agree that the native tongue allows for more efficient conceptual processing, there may be differences in the nature of that conceptual processing. Hunt and Banaji (1988) have suggested that there may be more cognitive effort required in one language than another, but other researchers have found this conjecture difficult to prove. The cognitive effort required to process certain mathematical word problems is high in English (Clement, Lochhead, & Monk, 1981; Cooper & Sweller, 1987; Lewis & Mayer, 1987; MacGregor, 1991). Similar research on mathematical word problems in other languages has occurred in Europe (e.g., Malle, 1993). However, *A guide to research on mathematics education* (Zhang, 1994) has no articles on language problems in mathematics in China,, although increasing research has emerged in Asian-English language comparisons (Cai, 1995; Galligan, 1997a; Li & Nuttall, 2001; Lopez-Real, 1997; Shen, 1997).

Chinese has been compared with English when investigating linguistic relativity (Bloom, 1981; Hoosain, 1991). The Chinese education system has also been the subject of comparative studies in mathematics (Byrnes, Hong, & Xing, 1997; Cai, 1995; Stigler, Lee, Lucker, & Stevenson, 1982; Stigler, Lee, & Stevenson, 1986). Apart from Cai's research, which found no difference between Chinese and English students for open-ended mathematical word problems, these studies have suggested Chinese superiority in almost all aspects of mathematics. This general superiority has been attributed to more time spent on the subject and to cultural and pedagogical differences (Byrne, 1989; Cai, 1995; Stevenson, Lee, Chen, Lummis, Stigler, Fan, & Ge, 1990; Stevenson, Lee, & Stigler, 1986). According to the Third International Mathematics and Science Study (TIMSS), other factors such as teacher confidence and knowledge of the subject, classroom interruptions, and an

examination driven curriculum may also have a bearing (Cheng & Cheung, 1999; Mullis et al., 2000).

Cross-cultural comparison between English and Chinese is interesting, particularly in mathematics, because there are notable differences in the language particularly in the orthography and the syntax. These characteristics of written language have been studied by researchers in cognitive psychology and psycholinguistics to determine their effects on the cognitive processing of ordinary prose. While most of the studies find that with general reading of text there appears to be no evidence for cognitive advantage in either language, in particular contexts and under certain circumstances, a cognitive advantage of Chinese over English is evident (Hoosain, 1991). If difficulties in mathematical text in English are due in part to syntax and semantics, do these same problems occur in Chinese? Do the orthographic characteristics or the phonological information in Chinese scripts influence the way in which text is processed?

With any cross-cultural research, because of the many variables involved, extreme care needs to be taken in drawing any conclusions from differences found. Au (1992) details some of these concerns. Shen (1997) makes a similar point specifically in the mathematics context, when he implies that some problem-solving strategies could be the result of different cultural values expressed through mathematics teaching. As he says, "it is the strategy of overwhelming practising that has led to the students forming a fixed way of treating every question with a single standardised model" (p. 65, translated).

Differences between English and Mandarin Chinese

While there are obvious differences between Chinese and English (Chang, 1992; Li, Bates, & MacWhinney, 1993; Li & Thompson, 1981; Newnham, 1987; Ramsey, 1987), research in cognitive science and psycholinguistic fields has not been able to show whether differences in languages have a differential effect upon cognitive processing. Flores d'Arcais (1992) has, for example, concluded that the available evidence does not seem to indicate dramatic processing differences for words written in alphabetic or logographic scripts. However, in a mathematical context, where syntax is often crucial to meaning (Dawe, 1993), and where a single word can give access to the concept image (Bell & Woo, 1998), any conclusions that may have been drawn from the cross-linguistic studies on cognition may not apply. In fact, Hoosain (1991) has suggested a link between processing and language in mathematics: "Although existing evidence is not conclusive in pointing at a direct causal role for a language related information processing difference, it is a distinctive possibility that should be borne in mind" (p. 75).

Research into language processing in English has enjoyed a relatively long history while the large majority of works about Chinese have appeared since 1980 (Chen & Tzeng, 1992; Huang & Li, 1996; Leong & Tamaoka, 1998), and the effect of many of the features of Chinese on processing is still being debated. There have been major changes in the Chinese language in the last 100 years and the influence of European languages is noticeable (Chen, 1993), however, major differences in syntax, phonology, orthography and semantics between English and Chinese languages are still evident. These differences are summarised in Table 1.

Table 1
English and Chinese Language Differences

Syntax	Orthography	Phonology	Semantics
Subordinate clauses	Number of words	Acquisition	Content words
Topic prominence	Morphological complexity	Word rules	Connecting words
Word order	Boundaries	Syllable structure and recall span	Context
Question structure	Character complexity	Sentences	
Possessive voice	Text density		
Markers	Types of characters		
Redundancy	Script layout		
Sentence type	Access to meaning		
Cues			
Conditional statements			

Note. No order of importance is implied in this table.

Syntax

Halliday (1984) has specifically compared English and Chinese mathematical language, and Lopez-Real (1997) and Galligan (1997b) have investigated syntactical differences in the context of mathematical word problems. The ten syntactic differences between English and Chinese listed in Table 1 may alter the complexity of semantic structures and hence have an effect on the processing of mathematical text.

Subordinate clauses and sentence length. There are few subordinate clauses in the Chinese language (Li & Thompson, 1981; Ramsey, 1987). In the past, Chinese used shorter sentences or linking attributes such as *de*. While some researchers have suggested that shorter sentences are still a feature of Chinese (Newnham, 1987), Chen (1993) has noted that in modern Chinese longer sentences are very common, using the word *de* as a connector. However, in many mathematical examples studied, shorter sentences are apparent. Here is one example:

一个正方形的对角线长10公分。找出这个正方形的边长.
Yī gè zhèngfāngxíng de duìji• oxiàn cháng 10 gōngfēn. Zhǎochū zhè gè zhèngfāngxíng de biānchǎng.
Translation (T): A square's diagonal length 10 cm. Find this square's side length.
English (E): Find the side length of a square whose diagonal is of length 10 cm.

Shorter sentences in English generally allow for easier understanding, and in mathematics it has been specifically identified as a desirable feature of mathematical texts (Austin & Howson, 1979; Wareham, 1993).

Topic prominence. Chinese is classified as a topic prominent language, as opposed to English which is subject prominent (Li & Thompson, 1981). For example:

这条线有多长.
Zhè tiáo xiàn yǒu duō chǎng?
T: This line has how much long?
E: How long is the line?

When reading mathematical text, the Chinese reader is immediately clued to the topic of the sentence, but not the relationship. In the above example, the Chinese reader is alerted to the *line*. In the English version, the reader is alerted to the *length*.

Word Order. While Chinese follows a subject-verb-object word order, similar to English. But, unlike English, Chinese noun phrases tend to be left-embedded (Chen & Tzeng, 1992). For example:

找出这个正方形的边长
Zhǎochū zhè gè zhèng fāngxíng de biānchǎng
T: Find this square's side length
E: Find the side length of this square

Left embedding may affect cognitive processing. From an English language perspective, researchers have found that readers must hold in memory the content of the descriptive clause before processing the sentence, which implies a greater cognitive processing load (Bloom, 1981; Casey, 1993). This may be a disadvantage for Chinese readers, but if it allows for topic prominence then the effect on processing may be more complex. In the example above, the English sentence first states what we want to find (the side length), then describes the referent (this square). However, the Chinese sentence places all of the possessive phrase (this square's side) first. Thus the person reading Chinese must hold in memory *this square's side* before reading the word *length*. Left embedding has been investigated by Chen (1992) in relationship to acquisition in English and Chinese for children learning their first language, and differences are apparent.

Research in mathematics education suggests that the positioning of information and the unknown in sentences may have an impact on the ease of processing the sentence (Lewis & Mayer, 1987; MacGregor, 1993); this effect is particularly true for comparison problems in English. Although Cai (1995) states that the relational proposition is explicitly shown in all comparison problems in Chinese, this may not be the case. The multiplicative example *There six times as many men as women* is translated syntactically into Chinese as *Men are women six times.* Here the relational proposition is clear. The similar additive compare problem *There are five more men than women* is translated as *Men compare women more five* . This sentence again suggests a clear relational proposition, but there is a subtle change in syntax. The change creates a semantic difference and there is evidence to suggest a difference in the processing in Chinese (Galligan, 1997b; Lopez-Real, 1997).

Another word order feature in Chinese which is different from English, is that used in the description of time and fractions. Chinese language is expressed from the general to the particular and from large to small. For example, consider these two examples:

一九九五年十月一日	百分之一
yī jiŭ jiŭ wŭ nián shí yuè yī rì	*băifēn zhī yī*
T: one nine nine five October one	T: hundred parts of one
E: 1st October 1995	E: one percent

The second type of example has been highlighted by Bell (1993) as important, since not only is the hundred stated first but the word *fen* means to divide. He suggested that these two features might provide a conceptual advantage to Chinese readers.

Question structure. There are four ways to indicate a question in Chinese. One common way used in mathematics is by the use of a question word, often placed at the end of a sentence. For example:

问明天星期几
Wèn míngtīan xīngqījĭ ?
T: Ask tomorrow is day what?
E: What day is tomorrow?

When compared with English, the syntactic structure of Chinese questions is much simpler (Chang, 1992). English question structure is more varied, and the change from the question to the answer requires changes to word structure and verb morphology. In mathematical word problems, students often find it difficult to unravel what the question is asking. The simpler syntax and more structured word order in Chinese may allow for faster access to the target question.

Passive voice. Chinese tend to make little use of the passive in mathematics. For example:

某数加上15后的21
Mŏu shù jia shàng 15 hòu dé 21
T: Certain number plus 15 later 21
E: When 15 is added to a number the result is 21.

The passive voice may require more processing time than the active voice. In English mathematical text, passives are common constructions and often involve the most difficult passive construction—reversible sentences (Slobin, 1973). For example, "x is subtracted from y" is considered reversible because x and y can be interchanged and the sentence still makes grammatical sense. In writing mathematical text in English, it has been suggested that passive constructions be avoided (Austin & Howson, 1979; MacGregor, 1988; Wareham, 1993). Chinese does have a character to indicate the passive, and it is a strong cue when it is used (Li, Bates, & MacWhinney, 1992). In recent years, the use of the passive construction has become a more common feature in Chinese (Chen, 1993); but it appears to be avoided when writing mathematics.

Markers. Chinese makes extensive use of extra "empty" words (Pollard, 1991) some of which are called measure words or markers. For example, in English we say *one shirt, one tie,* and so on, but *one **pair** of trousers*; the word *pair* is an empty measure word. In Chinese, a number (one, two, etc.) or a demonstrative (this, that, etc.) must always qualify a measure word. Thus, *two shirts* is translated as 两 件 衬 衫 *liǎng jiàn chēnshān* (two items shirt, *jiàn* being the measure word for shirts) and *9 divided by 4* becomes 9 分 除4 分 *9 fēn chù 4 fēn* (9 divided by 4 parts, *fēn* being a measure word to indicate parts).

This feature may have implications for the understanding of mathematical text. For example, when confronted with *9 divided by 4* in English, students may be uncertain as to which is the divisor and which is the dividend. In Chinese, the use of the measure word *fen* at the end could clarify this uncertainty.

Researchers such as Li & Thompson (1991) and Chen (1992) have suggested that Chinese makes little use of morphemes (i.e., the smallest meaningful unit of language) such as suffixes to indicate tenses, agreement markings, or plural markings on verbs and nouns. Instead of inflectional morphemes, Chinese has aspect markers such as 了 *le*, 这 *zhè*, and 在 *zài* (see Li & Thompson, 1981 for a detailed discussion). However, Chen (1993) has suggested that under the influence of European languages suffix-like morphemes have emerged, particularly in the field of science (Halliday, 1993). For example, continuity is translated as 继 续 续 *jìxùxìng* - 继 续 *jìxù* meaning *continuous* and 形 *xìng* being the morpheme *–ness.*

The general lack of inflectional morphemes and the inclusion of various markers may make the Chinese reader rely more on context that the English reader (Chen, 1992). Other research has indeed suggested that Chinese is more context-dependent than English (Arronson & Ferres, 1986; Chang 1992). Chinese text may be longer because of the markers, but the markers may act as an aid to understanding.

Redundancy. In general, Chinese is a much less redundant language than English (Aaronson & Ferres, 1986); but in mathematics this is often not the case. In English, words are often omitted if they can be inferred - as in the last sentence of *Ben is taller than George. Dave is shorter than George. Who is the tallest?* Wareham (1993) suggested that this feature increases the difficulty of reading English mathematical text. The Chinese translation of the last sentence is *Compare three men who is most tall.* This wording makes it clear that all three men have to be compared. The Chinese text may be more verbose than English and therefore reading times longer, but understanding may be clearer.

Sentence Type. Sentences which include verbs are the dominant sentence type in Chinese language. However, there are many common sentences in Chinese where the verb is omitted and the predicate consists of a noun, adjective, adverb, or phrase. For example, the English sentence: *Ben is taller than George* is translated into Chinese as *Ben compare George tall.* This type of construction, which is common in Chinese, has implications for processing. The English reader is first alerted to *Ben,* then to the relationship *taller than* (with the suffix *-er* telling the reader a comparison is being made), and then to *George.* In the Chinese version, the reader is first alerted to *Ben,* then to the fact that a comparison is to be made to *George,* and

finally to the attribute *tall*. The English version first creates an image of the tallness of Ben, while the Chinese version first creates an image of the two people.

Cues. In understanding mathematical text, word order and cues are crucial. For example, *9 is divided by 4; divide 9 by 4,* and *4 is divided into 9* all convey the same meaning in English but may not require the same processing. Not only is the word order important, but the cues *by* and *into* are crucial. Although word order seemed to be the most important component of Chinese syntax, recent research suggests that it is not as important as it was once thought and that it not as important as in English. Cues in Chinese are significantly different from those in English (Li et al., 1992; 1993). For example, while Li et al. found that the most reliable cue to sentence interpretation in English was the pre-verbal positioning of the subject, it was the post-verbal cue to the identification of the object which was stronger in Chinese. However, they concluded that several cues are used in Chinese to interpret sentences including passive marker, semantic, syntactic, and semimorphological cues.

Conditional statements. Chinese does not have any specific grammatical tool to indicate the counterfactual conditional, as in *How much string would have remained if 3 cm had been cut from it?* Li and Thompson (1981) argue that a specific distinction is not necessary since the context alerts the reader to the type of conditional. There has been much debate on this topic (Bloom, 1981; Au, 1983; L. G. Liu, 1985; Liu, 1986; Hunt and Banaji, 1988), but it appears that this type of reasoning is difficult in every language.

The above syntactical characteristics of written Chinese in mathematics compared to English may all have an effect on efficiency of processing. Yet few of these have been researched in relation to mathematical text. Further research in this area would assist both English and Chinese mathematics educators to understand of the role of syntax in processing mathematical text.

Orthography

When a comparison is made between English and Chinese, it is the orthography of Chinese writing that is most evidently different from English. While syntax and semantics play a crucial role in the understanding of mathematical text, the orthography of a language provides a window to meaning. Since mathematics is largely communicated by written text, orthographic characteristics are a crucial part of mathematics communication. However, it is still unclear what impact these differences may have on the processing of mathematical text. For example, what are the implications in such areas as dyslexia and visualisation in mathematics?

In the mathematics education literature, apart from Zepp (1989) who devoted a chapter to differences between an alphabetic and logographic script, and Li and Nuttal (2001) who investigated the relationship between writing Chinese characters and mathematics achievement, little attention has been paid to the orthographic features of the language. However, when investigating the orthography of Chinese a number of characteristics emerge which may have implications for cognitive processing. Eight differences between Chinese and

English orthographies are discussed below.

Number of words/characters. There are approximately 4,000 characters normally used by literate Chinese. However, only 2,460 characters are needed to account for 99% of the 1,177,984 Chinese character corpus. For the equivalent one million English corpus, about 40,000 English words are needed (Chen, 1992). Because there are fewer characters used to write Chinese, the meaning of individual characters are more variable and hence context is more important.

Morphological complexity. Chinese characters correspond to only one syllable in the spoken language. While it is not fully monosyllabic, it is considered an isolating language, where a word consists of just one morpheme. This characteristic reflects, in part, the lack of inflectional morphemes For example, instead of saying *coldest,* Chinese say *most cold.* While there is some disagreement in this area, researchers tend to agree that there is little morphological complexity in the language.

Boundaries. The character boundaries, not the word boundaries, are marked in written Chinese. In the following example, there are six characters but only four words (although 星 期 could be classified as two words):

问 明 天 星 期 几
Wèn míngtīan xīngqī jǐ
T: Ask tomorrow is day what?
E: What day is tomorrow?

Thus, in Chinese, the character appears as the basic perceptual unit in reading, as opposed to English where the word is the perceptual unit. Chen (1992) supports this view and provides a brief summary of the research in this area.

Character complexity. A Chinese character occupies the same area, no matter how complex the word. For example, the word 人 *rén* has only two strokes, but the word 楚 *chǔ* has 13 strokes. The variation is especially significant in traditional Chinese, where there can be up to 29 strokes in one character. In traditional Chinese, the word for *what* or *how many* consists of 11 strokes; the simplified character has only two strokes.

The complexity of a Chinese character does not affect the length of the basic textual elements in the same way that complex English words do. Huang and Wang (1992) found that there are no studies directly applicable to the role of spatial compactness in character recognition, but suggested that no effects should be found since the characters are "overlearned semantic units" (p. 6).

Text density. English text may be 50% longer in terms of the printed length (Liu, 1986). The difference is due not only to the composition of the individual textual elements, but also to different redundancy characteristics. Although the printed text is much more dense in Chinese than in English, it takes about three times as long to write a Chinese page (Liu, 1986). While it may appear that Chinese script would be faster to read, the density of the script may slow this down.

Types of characters. Chinese has four categories of characters. The three least common are pictograms (日 *rì*, meaning *sun*), symbolic words (下 *xià*, meaning

below), and associatives (好 *hǎo*, meaning *good*, literally woman + child). The most common category consists of the phonetic compounds or pictophonetic characters, which form about 90% of modern Mandarin (Hoosain, 1991). For example, 河 *hé* means river. The left-hand side of the character 河 is the meaning element, so many words to do with water have this as a component. Embedded in the right-hand side of 河 is the phonetic element (the box like shape). For example, 和 (meaning *and*) is also prounounced *hé*. However, these phonetic compounds are not rule governed (e.g., 柯 , which has the same phonetic component as 河 *hé*, is pronounced *kē*). Direct syllabic to phoneme transfer occurs in only a minority of cases.

Script layout. Chinese script can be written either from left to right or from top to bottom, and characters themselves can be configured in up to 15 different ways. For example, 和 *hé* (meaning *river*) has the semantic component on the left and the phonetic component on the right but 想 *xiǎng* (meaning *wish*) has the semantic component on the bottom and the phonetic on the top.

Thus Chinese readers tend to scan a word in two dimensions (Huang & Wang, 1992) and write in two dimensions (Li & Nuttall, 2001). It is this characteristic of Chinese script layout that Li and Nuttall suggest facilitates Chinese students' spatial skills and could therefore account for their greater geometry achievement.

Access to meaning. Chinese students may have more direct access to the meaning of written texts. For example, Chinese people can understand much of what is written in other Asian languages which use the same script base. They can also understand ancient Chinese scripts, accessing the correct meaning while using modern pronunciation. Students studying Chinese often access meanings of words from script without remembering the Chinese pronunciation, and Chinese readers can recognize the semantic content of characters without being able to understand them (Chen, 1993).

When the orthographic, semantic, and phonological lexicon of the specific languages have been developed in memory, the problem is to access the words and their meaning. How memory accesses words is still unclear (Samuels, 1994). It may be through visual, phonological, or an automatic process, or some combination of these, and this process may not be universal for all languages. Researchers in the past have assumed direct access (Samuels, 1994). While conceding that phonological coding does take place, Hoosain (1991), argued that the particular nature of logographic script allows readers to access the direct meaning of words without going through the sound first.

The importance of orthography in reading and processing mathematical text cannot be overlooked in mathematics education. This is especially true in early childhood where children are learning to read everyday and mathematical text. For example, the word thirteen in Chinese is 十 三 (ten three) and the word twenty is 二 十 (two ten). Similarly, the word for Tuesday is 三 天 (three day), for March is 三 月 (three month), and for triangle is 三 角 形 (three corner shape).

Orthography is a main contributor to the activation of the meaning of words and the more easily and quickly these words are activated, the easier it is for the text to be processed.

Phonology

Phonology also contributes to the activation of the meaning of words and sentences because, in the processing of written texts in mathematics, students often vocalise or sub-vocalise the text. The phonology of Chinese has a number of characteristics which are different from English (Leong & Tamaoka, 1998).

Acquisition. In the early stages of learning any subject, including mathematics, young students are still acquiring language and learning language structure. How they do this is different in different languages (Slobin, 1985, pp. 3-19). In their experiments on understanding words in isolation, Muter and Johns (1985) found that learning a script based on pictures was dramatically easier than learning an unfamiliar alphabetic code. When students learn to read in Chinese they seem to depend much less on phonological awareness skills than students learning to read English, and it seems that learning to read Chinese is much more closely related to performance on a test of visual skills (Huang & Hanley, 1994). While the nature of reading problems in Chinese children is quite different from those of English readers (Hoosain, 1992b), when students become more expert in the language it is unclear if they have the same dependence on phonology and visual skills.

Phonetic rules for words. While most words in Chinese are phonetic compound words, the phonetic component is not rule governed and each phoneme has to be learned individually (Hoosain, 1991). For example,们 pronounced with a rising tone (*mén*) means *door* whereas 们 pronounced without the rising tone (*men*) is a plural for pronouns. In this case, the two words have the same sound but a different meaning. But the component 门 is also contained in 间 *jiān* (the measure word for *room*) and 问 *wèn* (meaning *ask*), which have different sounds and different meanings.

Chinese language is extensively homophonic, with 11 characters on average sharing the same pronunciation (Tan & Perfetti, 1998). For example, 阅 (meaning *read*) and 悦 (meaning *happy*) are both pronounced *yuè*.

The position and complexity of the phonetic and semantic components may have implications for ease of reading and understanding Chinese script.

Syllable structure and recall span for words. Research suggests that there is a positive linear relationship between articulation rate and short-term recall span (Baddeley & Lewis, 1981). However, this relationship is not the same in English and Chinese. According to Cheung and Kemper (1993), the lack of consonant clusters contributes to the articulatory advantage of one-syllable Chinese words over one-syllable English words. Moreover, Chung and Kemper suggest that a visual iconic may also contribute to an enhanced recall of Chinese words.

These last two features may have implications in mathematical text, at least for numerals. Chinese numerals are more regular, pronunciation is based on one syllable, and a visual iconic is clearly available for some numbers (e.g., 一 二 三 for 1, 2, 3).

English readers may use phonological representation more and the visual representation may be more important for the Chinese readers (Cheung & Kemper, 1993; Huang & Hanley, 1994; Samuels, 1994), but there are still many unresolved

issues.

Since English letters map in a large part onto phonemes, English may have the advantage in phonology generally. However, Cheung and Kemper (1993) claimed that differences in phonology and the syllabic structure of Chinese and English affect the encoding process and the articulation rate, suggesting an advantage for Chinese, at least with one-syllable words. But any difference between the two languages becomes more difficult to prove when sentences need to be read or the context becomes more specific—as in mathematics, where many polysyllabic words are used in both languages.

Sentences. How memory is used to process sentences is not fully understood, but research is heavily dependent on theories of word processing (Adams, 1994). In these theories, orthography and syntax are still important but phonology and semantics become essential elements. Phonological processes are important when storage of information and processing to a greater depth is required (Hoosain, 1991), and they may provide a back-up for recognising less familiar words (Adams, 1994). Phonological processing occurs with many mathematical word problems, especially when vocalising or sub-vocalising is used to help to access meaning. While phonetics plays an important role in identification of individual words in alphabetic script, it is still unclear whether it has the same role in Chinese character or word identification. Hoosain (1991) believes that "getting at the sound of characters could be slower, without the grapheme-phoneme conversion rules, but getting at the meaning of individual words is in turn more direct" (p. 166).

When reading mathematical text, if phonology is not always employed, then Chinese may have faster access to words since script indicates meaning more directly (Chen, 1993). However, if phonology is automatically activated, then this could slow down reading of text. It is important to include phonology in any research involving language and the understanding of mathematical text.

Semantics

A discussion on semantics inevitably touches on syntax, orthography and phonology, so some semantic issues have already been discussed in previous sections. However, access to meaning can also be related to the content of the words themselves and the way in which sentences are processed through the context.

The influence of the word on understanding and processing of concepts cannot be overlooked. The Vygotskian view that there is a "continual movement back and forth from thought to word" (1962, p.125) is a pervading one. While the word may only supply the reader with access to the concept definition (e.g., *diameter*), it may help to access the total cognitive structure (i.e., all the words which associate with the word *diameter*). Therefore the way in which those words are assembled and presented, and the way they sound, may contribute to the ease with which we can get to the concept.

In general, meanings of words and characters on their own in Chinese are less precise and more variable, and individual words in sentences carry less meaning and structural information than in English (Aaronson & Ferres, 1986; Chen, 1992).

This is largely due to the smaller lexicon in ordinary usage. However, a written Chinese character has more direct connection with its meaning than a word in English (Tan & Perfetti, 1998). Individual words still play an important part in conveying meaning both individually and in a sentence. Connecting words such as prepositions and conjunctions are important, but content words are crucial. This becomes especially important in the field of mathematics, where every word can convey important meaning. Many concepts can be represented by single words (e.g., *fraction*) and the concepts themselves are often abstract (Bell & Woo, 1998). There are also some differences between Chinese and English written word structure that may have an effect on the way words allow access to concepts.

Content words. While there are many compound words in English which clearly indicate meaning, Hoosain (1992b) and Li and Thompson (1981) suggest that they do not compound as productively as they do in Chinese. Moreover, compounding is used in English for nouns while in Chinese it is used for many classes of words (Hoosain 1992b). Many Chinese compound words describe things rather than label them. This feature is particularly evident in mathematics and science, where the meaning is clear from the examination of the characters. For example, *diameter* is 直径 *zhí jìng*, meaning straight distance, and *radius* is 半径 *bàn jìng*, meaning half distance.

In mathematics and science, where taxonomies are common, many words are based on hyponymy ("is a kind of"). In Chinese, hyponymic sets are constructed much more regularly than in English (Halliday, 1984). English use of taxonomies tends to be based on Greek or Latin roots, making them less accessible than Chinese words (see Table 2). For example, Chinese names for shapes all have 形 *xíng* (meaning *shape)* as the last character.

Table 2
Examples of Chinese Compound Words Which Indicate Meaning

Chinese	English	Pinyin	Translation
三角形	Triangle	*sān jiǎo xíng*	Three corner shape
四边形	Quadrilateral	*sì biān xíng*	Four side shape
可变数	Variable	*kěbiàn shù*	Change number
不可变数	Constant	*bùkebiànshù*	No change number
分子	Numerator	*fēnzǔ*	Fraction son (child, seed, or young)
分母	Denominator	*fēnmǔ*	Fraction mother (female or origin)

Other words. It is not only content words that are important in understanding mathematical word problems, but also logical connectives (Esty 1992). For example, Chinese has more than one word for *if*, and anecdotal evidence suggests that the word *only* may have different contextual meanings from those in the parallel English sentence.

Context. While Chinese may have some advantage in retention due to the syllabic and some of the phonological structure (e.g., numbers), it seems that

generally the time taken to read sentences is the same for both languages (Hoosain, 1991). However, researchers in English have agreed that just reading a mathematical word problem does not give the reader sufficient understanding to solve it (Jones, 1982).

From investigations into syntax, orthography, and phonology, many researchers now agree that Chinese is more context-dependent and less word-dependent than English (Aaronson & Ferres, 1986; Chang, 1992; Chen, 1992). From his research on undergraduate students, Chen concludes that "Chinese and English languages activate different processing strategies for reading comprehension such that Chinese text induces a diffused strategy and English a more focussed strategy" (p. 175).

In the context of mathematics, the question could be posed: Do Chinese processing strategies have an impact on the way Chinese students understand mathematical text and, in particular, solve mathematics word problems?

Words which clearly convey meaning help make mathematics accessible. Whether Chinese mathematical words do this better is a possibility which needs to be investigated further. On the other hand, context is also important in mathematics - especially with mathematical word problems and problem-based learning. Context plays a more critical role in reading and comprehension in Chinese, and readers rely less on individual characters, words or grammar in general reading. Moreover, their holistic view of reading as opposed to a more focussed view activated by English readers, may help with their reading of mathematical word problems. Again more research in this area may shed light on the relative importance of words and context in relation to meaning in mathematical text.

Discussion

It is evident that Chinese differs from English in many aspects, and that these differences may have an impact on cognitive processing. However, the relative strength with which these features influence mathematics learning is still unclear.

Mathematical text in any language is extremely dense, contains specific technical vocabulary, and uses ordinary words in a specific way. Processing sentences in such a linguistically dense context, coupled with the logical nature of many mathematics problems, requires the reader to rely on the sentence to convey clear and unambiguous meaning. Hence words that help to convey meaning or allow the concept image to be formed more readily, and a sentence structure that allows word problems to be easily understood at a surface level are important components in any language. These same features may also be important when attempting to understand word problems at a deep level, and hence to aid the solving of these problems.

Further Research

Mathematics educators and others have suggested that, for certain areas of mathematics, language is an important component in facilitating or inhibiting students' access to concepts. The way students read, the syntactical structure of

sentences, relational statements, density of sentences, passives, order of sentences, logical connectives, and vocabulary, have all been identified as potentially hindering conceptual understanding. These difficulties, combined with the actual cognitive load placed on short term memory while trying to process mathematical text, make the solving of mathematical word problems particularly difficult. While there has been much discussion on word problems in the mathematics education literature related to language (mainly in English), these problems may not manifest themselves to the same degree in Chinese. From the earlier discussion and the mathematics education literature, answers to the following research questions would provide a clearer picture of the exact role of language in understanding mathematics.

Accuracy in reading. Students reading mathematical text in English do not read accurately and tend to "skim". Does the same happen in reading Chinese, or do readers read more carefully and accurately because they have to rely on context more than readers of English? Researchers have compared how students read in Chinese and English by analysing what students focus on while reading (Chen, 1992; Li et al., 1993). This technique could be applied to the reading of mathematical text to order to identify different strategies and to identify specific words, phrases, or syntactic structures that students rely on to assist in the understanding process. Care would need to be taken in choosing appropriate text to ensure that there are similar "trick" and "routine" questions.

Syntactic structure. Chinese syntactic structure is simpler and more regular for mathematics than English. Does this mean that readers of Chinese have faster and more accurate access to the meaning of mathematical text such as relational word problems and transitive inference problems? Studies by Galligan (1997b) and Lopez-Real (1997) have outlined differences in syntactic structure and provide some evidence for clearer understanding in some circumstances and of different strategies being used in other circumstances. However, more thorough studies need to be undertaken.

Passives. Does the lack of passives in Chinese facilitate faster access to meaning? While some mathematics educators have suggested passives should be avoided, the non-use of passives may remove some of the flexibility that is characteristic of the English language. Comparison in this area is difficult, since constructing a passive statement in Chinese mathematics can be seen as 'unchinese'. A small study comparing an active statement in Chinese with the corresponding passive statement in English produced, not unexpectedly, more inaccuracies in the English version (Galligan 1997a).

Density. Does the higher density Chinese script allow students to read mathematical text better or faster than their English counterparts? While there have been some comparative studies employing non-mathematical script, it would be interesting to replicate some of these studies in the context of mathematics word problems. Two difficulties here are to separate the reading from the understanding and to measure the speed of each skill.

Word order. Does the word order in a sentence have the same impact on the

Chinese as the English student? For example, the order of words in the problem *That man's father is my father's son. Explain.* (Casey 1993) may be at least partly responsible for its difficulty level. A change in syntax within a language changes the ease with which a student can access its meaning, an effect which has been researched in relation to English mathematical text (e.g., Lewis & Mayer, 1987). But does the same syntactic change produce similar results in other languages? A study by Galligan (1997b) suggests that it does - but not necessarily in the same manner, since other variables (such as context and sentence cues) may also be changed. The implications of this finding are important in any cross-cultural study in mathematics. Comparing two problems which appear to have the same mathematical and linguistic content may impose different loads on the students being tested.

Logical connectives. Is there any difference between using and understanding logical connectives? For example words such as *and, or,* and *only* have particular importance in mathematics. A study into the comparative use of these words in Chinese and English would provide valuable insight into their impact on understanding.

Mathematical words. Does the regular and more descriptive naming of many words in the mathematics register provide any advantage for the Chinese reader? Work by Bell and Woo (1998) has indicated that different words do produce different connotations in Korean and English. They suggest more research is needed in this area.

There has been some evidence for a Chinese language advantage with respect to number sense (Fuson & Kwong, 1991; Hoosain, 1991; Miura, Okamoto, Kim, Chang, Steere, & Fayol, 1991; Stigler et al., 1986) and the possibilities have begun to be researched with fractions (Bell, 1995), logical connectives (Zepp, Monin, & Lei, 1987) and relational word problems (Galligan, 1997a; Lopez-Real, 1997). However, the literature review and the questions posed in this article suggest that more research is needed. Any such research would have implications for cross-cultural studies comparing mathematical abilities, such as the next International Mathematics and Science Study. When comparing mathematics in different countries, while there are many factors to consider (e.g., social, political or pedagogical differences), language differences may also be crucial. Just getting the language right does not necessarily imply that the content conveyed by that language is unchanged.

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