Creating words in mathematics

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Introduction

A *National Numeracy Report* (COAG, 2008) and the *Australian Curriculum* (2014) have recognised the importance of language in mathematics. The general capabilities contained within the *Australian Curriculum: Mathematics* (2014) highlight literacy as an important tool in the teaching and learning of mathematics, from the interpretation of word problems to the discussion of mathematics in the classroom. The nationally commissioned *National Numeracy Report* (COAG, 2008), recommended that the language and literacies of mathematics be explicitly taught since language can be a significant barrier to understanding mathematics. As teachers routinely assess students' understanding of mathematics through literacy (often through reading and writing), students may struggle to understand the mathematics because they have specific language difficulties associated with assessment tasks set. Chapter 2 of the *National Numeracy Review Report* highlights the role of language in mathematics learning, and identifies a number of features of language that can have an impact on understanding mathematics. These include:

1. **The mathematics register:** the words, phrases and associated meanings used to express mathematical ideas (Halliday, 1978). This includes the etymology of the words of mathematics as well as the syntax, semantics, orthography and phonology of the language itself and its impact on understanding mathematics (Galligan, 2001).
2. **Language in the classroom:** the use of language by teachers to communicate ideas and the dialogue used by students to communicate and learn mathematics (Leung, 2005; Sullivan, 2011; Walshaw & Anthony, 2008). This language use is particularly difficult for English language learners (Adoniou & Yi, 2014).
3. **Technical communication:** the accepted standard use of language and symbols to communicate mathematical ideas, both orally and in written form. There are Australian Standards on how to write much of the quantitative information in scientific and technical reports, and also in trade and industry (Australian Government, n.d.).

This article focuses on one part of the first feature; that is, words in mathematics, their derivation and meaning.

Words in mathematics

Having the correct word for a concept provides immense assistance in the understanding of that concept, as well as minimising the burden on working memory, and also greatly increases the power of the mind to use that concept (Carroll, 1964). In fact Vygotsky (1962) believed that, for an individual, a concept does not attain for the individual an independent life until it has found a linguistic embodiment. While it is unlikely that words themselves determine the way different cultures view the world—termed 'linguistic determinism' by Whorf (1956)—language is a window to concepts different cultures hold important. When new concepts are introduced into a culture, new words are then developed, tried, discarded or embraced into the lexicon.

There are a number of ways new words come into language. The following describes some ways these can occur, suggests reasons why they occur in this way, and reflects on some of the consequences of the choices. The examples below come from mathematics, as words in mathematics are of particular importance. Since concepts are often encapsulated in words, the adequate grasp of the correct terminology in mathematics, according to Austin and Howson (1979), is a prerequisite for cognitive function. This has particular importance in countries that embed formal mathematical ideas into their culture. While the choice of the word can assist people gaining access to meaning, it can also cause misinterpretation of the essence of the concept. The examples given below, while mainly in English, will also be from Chinese, as well as Maori and other Pacific Island nations where the mathematics register is still developing.

Derivational processes

Derivational processes are the most common way a new word comes into the English language (Yale, 1996). These new words are produced by affixes (prefixes, suffixes and infixes). The word 'bunk', for example, was the basis of a new word 'debunk' (using the prefix de-), which was coined in 1927 (Yale, 1996). There are many words in mathematics that are produced this way. Epicycloids—curves generated by a point on the circumference of a circle (the epicycle)—or hypocycloids (Figure 1)—curves that roll on the inside of the circle—are examples of adding prefixes and suffixes. The cycloid was first coined by Galileo (Schwartzman, 1994), and comes from circle with the '–oid' suffix used in the sense of 'having to do with'.

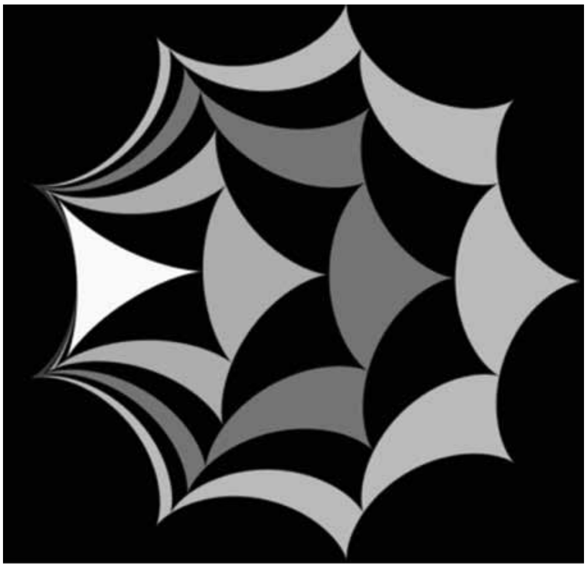

Figure 1. Hypocycloid generated from *GeoGebra* (Christersson, 2015).

While these derivational processes are common in English and other European languages, they were not as common in Asian languages such as Chinese. However, with the influence of European languages, particularly English (Chen, 1993), they are becoming more common. This is particularly true in the sciences (Halliday, 1984). For example, continuity is translated as ‘jìxùxìng” 继续 where ‘jìxù’ means continuous and ‘xìng’ is a morpheme that roughly translates as the suffix “–ness”.

In English, a variety of morphemes are available to create new words, so it is interesting to see why one combination is chosen over another. For example, in mathematics, a ‘derivative’ is a rate of change coming from the word ‘derive’, yet to do the calculation employs ‘differentiation’. The reason it appears in calculating the derivative, is to actually look at the difference in the quantities (Schwartzman, 1994). While the choice of this word may have been to aid in concept understanding, it is probably lost on many struggling mathematics students.

Coinage

Coinage is the invention of a non-derivational new term, and is one of the least common ways to introduce new words (Yale, 1996), sometimes called neology. For example, Kasner’s son created the word ‘googol’ when his mathematician father asked him the name of a large number. The word ‘googol’ is now the name of the digit ‘1’ followed by one hundred zeros. Why did the googol become more acceptable than using the more common derivational process by choosing a number with Greek roots? The number 10^{102} is a septendecillion since it is $(10^6)^{17}$, or a million raised to the 17 (Gullburg, 1997). It could be that it was not easy to find a regular equivalent since six does not divide into 100 exactly, or it was simply that usage of large numbers may now be more common, and a more accessible word was needed. There are no other words in mathematics that have been coined, in the neological sense, but perhaps students may have fun inventing some.

Acronyms

Acronyms are words derived from the initials of a collection of words. Sometimes they become words such as radar (from radio detecting and ranging) or sonar (from sound navigation ranging). In either case, the capitalisation has been lost. Sometimes they are used as an abbreviation for a name or expression. FAQ (Frequently Asked Questions) is an example where capitals remain and are pronounced as the individual letters. Others, such as PIN (Personal Identification Number), are pronounced as real words, but capitalisation remains. In mathematics, the acronym QED (Quod Erat Demonstrandum) which means “which was to be demonstrated” was borrowed from Latin, and is used at the end of a mathematical proof when it has been completed. There are other acronyms which are more locally used, such as APs and GPs (Arithmetic and Geometric Progressions), DNE (Does Not Exist) and DNF (disjunctive normal form), which may be found in mathematics dictionaries (for example, Borowiski & Borwein, 1989), but not in ordinary English dictionaries.

Back-formation

Back-formation is used when new words develop from other words by reducing them. In this case a word, usually a noun, is used to form a verb. The word television was created and then the word televise arose from it (Fromkin, Blair, & Collins, 1999). One common example of back-formation is the assumption that if a noun has –er on the end then a verb can be created from it. Yale (1996) describes a particular form of this as hypocorisms. Here a longer word is reduced to a single syllable then –y or –ie is added to the end. Nouns can also be formed from adjectives. For example, in mathematics, ‘evaluate’ is a back-formation of ‘evaluation’, ‘statistic’ from ‘statistics’, and ‘quantitate’ from ‘quantitative’ (Merriam-Webster Dictionary, 2015). The word ‘topos’ is a back-formation of the word topography and was used first by Grothendieck in the 1940s to describe 'sheaves' in topological spaces (J. L. Bell, 2006). Figure 2 shows a topo example for a small stellated dodecahedron (Judge, 2015). A sheaf in mathematics is metaphorically connected to the original meaning of the word. That is, a bundle of cut and bound stalks, as it is a "collection of planes passing through a given point." (Schwartzman, 1994).

Figure 2. Topo small stellated dodecahedron (Judge, 2015).

Clipping (or abbreviations)

Clipping (or abbreviations) of words can emerge into the lexicon. This is when words of more than one syllable are shortened; for example piano is short for pianoforte. The word mathematics is clipped to maths or math. In trigonometry (often shortened to trig), the ratios sine, cosine and tangent are clipped to sin (still pronounced as sine), cos and tan. Originally the word graph in the nineteenth century was graphic formula and was shortened to graph; in number theory a 'repdigit' (repeated digit) is an integer composed of one digit only, as in 555 or 999999 (Schwartzman, 1994); and a directed graph became a 'digraph', although who first used the word is unclear—perhaps as early as 1847 by De Morgan (Black, 2008). Figure 3 provides a visual digraph representation of a network of connections between devices within the Internet (Nykamp, n.d.).

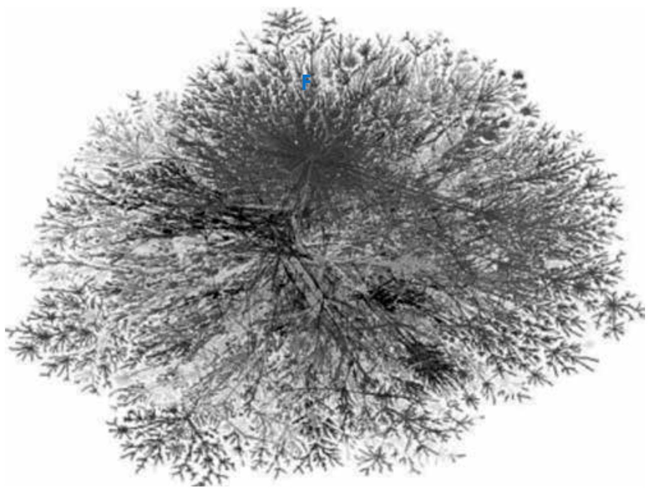

Figure 3. Digraph of network of connections between devices within the Internet (Nykamp, n.d.).

Conversion (or functional shift)

Conversion occurs when the function of a word changes, without reduction. Often this occurs when a noun changes to a verb. This is common in modern English (Yale, 1996) and can also be used to change verbs into nouns. In mathematics, an example from a verb to a noun occurs when we ask students to “graph the function”, and then draw the “graph of the function”. An example from a verb to an adjective is when we ask students to “round the number 37.45 to the nearest whole number”, thus 37 is a round figure.

Borrowing

Borrowing is one of most common ways new words come into a language, yet it can have profound political and social ramifications. Many words enter a language as new technologies or ideas are introduced from other cultures. For example, algebra is from an Arabic word ‘al-jabr’ meaning the reunion of borrowed parts (Schwartzman, 1994). However what happens when a new way of thinking enters a culture? Modern mathematical ideas introduce many new terms. Culture can be overwhelmed by this new register to the extent that the whole of mathematics appears foreign and not owned by the culture. This can be exemplified by the Maori experience. Borrowing had been used in Maori language in mathematics (Meaney, Trinick, & Fairhall, 2011) until an extensive language development program (Maori Language Commission, 1991) attempted to develop new words which embedded semantic meaning into them allowing for increased or faster access to the concept. Mathematics educators went to the Maori community actively seeking appropriate words. For example, instead of using the word diameter, they introduced the word ‘hokai’ which is a diagonal-crossed braces to keep an eel pot open. Figure 4 provides a visual representation of a Maori eel pot (Best, 1929).

The borrowing of English words in languages has in recent times been resisted by many cultures. A UNESCO mathematics conference (UNESCO, 1991), highlighted some of the native language movements in the Pacific. In Niue, where vernacular language is still used, the word for spoon was ‘sipunu’ or for motor car was ‘motoka’, but locals are encouraged to use the Niuean words ‘helu’ and ‘peleo afi’. In Tonga many words are borrowed, where commutative becomes ‘komitativi’, and multiple becomes ‘malatipolo’. A special type of borrowing is described as loan-translation (calque) where there is a direct translation of the elements of a word into the borrowing language. This can be seen in mathematics. For example, in Maori words have been derived from the definition of the ‘pakeha’ term. The word square is ‘tapawhā rite’, four equal sides. (Karetu, 1991).

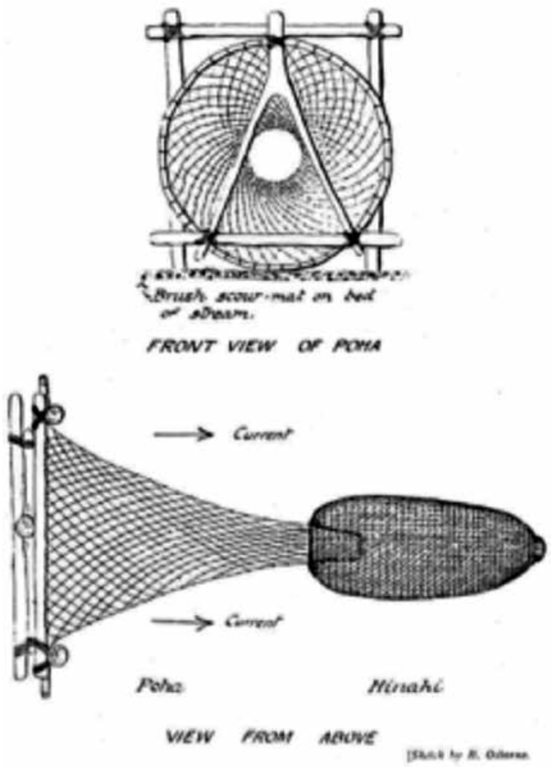

Figure 4. Maori eel pot (Best, 1929).

This particular area of language development, highlights the importance of language as it impacts on social and political change The artificial social construction of the mathematics register, as in Maori and other Pacific Island cultures, is a relatively new experiment and the lasting impact on the development of mathematics understanding, or on the wider social or political agenda is yet to be realised. It does at least exemplify the importance that some cultures place on the right word.

Compounding

Compounding is the joining of two separate words to form a new word. Sometimes these words do not always mean the sum of the two words, so a blackboard is not always black. English compounds more commonly for nouns, although adjectives and verbs do exist (Hossain, 1992). Seventeen is the combination of seven and ten. While the many compound words appear logical and naturally assist in the understanding of the underlying concept, this is not always so. For example, the compound words in English for many numerals are not as regular or logical as in other languages. In English, the word fourteen is translated as ten four in many other languages, which may have consequences in the manipulation of those numbers. Fuson and Kwon (1991), suggests that many Asian number systems, which compound regularly, assist young children in the understanding and manipulation of numbers.

English compounds more than other languages, such as Spanish or German. However, English words do not compound productively like Chinese (Li & Thompson, 1981). Chinese compound for many classes of words[1] (Hossain, 1992), and they tend to describe rather than label, and the way they compound may also have implications for understanding. For example, the words 'fraction', 'numerator' and 'denominator' are in Chinese 'Fēnshù' 分数, 'Fēnzǐ' 分子, 'Fēnmǔ' 分母 respectively. The words 'zǐ' and 'mǔ' mean son and mother. In this case, the compounding has added connotational meaning with the analogy of the relationship between son and mother. Moreover, the way many Asian languages denote fractions may have implications for ease of understanding (G. Bell, 1993). The word three-quarters in Chinese is literally four fraction (fen) three. The whole part of the number is said first, and the word 'fraction' is part of the compound word.

Many mathematical words are compounds which had Greek or Latin roots. For example, 'parabola' in English, comes from Greek para 'alongside, nearby, right up to' and –bola, from verb *ballein* "to cast, to throw" (Schwartzman, 1994, p. 158). So to get easy access to the meaning, students need a lesson in ancient Greek. These types of words have been referred to as 'dead metaphors'. In contrast, the corresponding word in Chinese is: 抛 物 线 , which literally means 'throw object line' (no intermediary language required). This comparison is not just interesting information. Research (Durkin & Shire, 1991; Ellerton & Clements, 1996) suggests characteristics of the English language have a negative effect on students' performance in mathematics, particularly the processing of mathematical text. Words are the gateway to understanding and processing concepts in mathematics and we continually move back and forth from thought to word. (Vygotsky, 1962, p. 125).

Take the word 'diameter'. While the word may only supply the reader with access to the concept definition, it may help to access the total cognitive structure, that is, all the words which associate with the word diameter such as radius. So in Chinese (zhíjìng 直径) literally meaning 'straight path' and radius as bànjìng (meaning 'half path'), allow for more direct access to meaning for both words.

1. Compounding in Chinese is controversial, as the meaning of a word in Chinese is fuzzy (Tan, Hoosain, & Peng, 1995). The character, and not the word, is the basic perceptual unit of Chinese language and so many words tend to be multimorphic.

In the mathematics register in Maori, the word for factor 'tauwehe', is a combination of the word 'tau' meaning number, and 'wehe' meaning to divide. 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. If that gateway is more difficult, then a role of the teacher is to open that gateway to better understanding.

The names of number words may help or hinder early learning. For example, twelve and thirteen are not part of a regular named-value system. In contrast, in some Asian languages such as Burmese, Japanese, Korean and Thai, number words are said and then the value of that number is named (5726—five thousand seven hundred two ten six) (Fuson & Kwon, 1991, p. 211). In addition the *orthography* of the language may assist in the reading and processing of text. For example, the word thirteen in Chinese is 十 三 (ten three) and the word twenty is 二 十 (two ten); the word for Tuesday is 三 天, for March is 三 月, and for triangle is 三 角 形. (Galligan, 2001, p. 121). Again, if a teacher can highlight these structures to students who are struggling it may assist their understanding of the subject, particularly around the concept of place value.

Eponyms

Words from names are called eponyms. The Cartesian plane, a rectangular coordinate system, comes from the 17th century mathematician Rene Descartes. The Gaussian method of elimination is used in matrices and comes from the mathematician Gauss. Pythagoras' theorem is named after the Greek mathematician Pythagoras. While this theorem was known by other civilisations (so not invented by him), this word has been borrowed by many other languages. In mathematics, words such as these provide an excellent way of showing students the history of mathematics and may help in the understanding and remembering of concepts.

Blends

Blends are produced when parts of two words are combined, usually the beginning of one word and the end of another. Yale (1996) has some interesting examples, including Franglais which is a combination of French and English. In mathematics, a googolplex is a blend of the word googol and duplex. Since a googol is a number 1 followed by 100 zeros, a googleplex is a number 1 followed by a googol of zeros. Sinh is a hyperbolic function, from two words sine and hyperbola.

Semantic shift

Semantic shift occurs when words take on new meaning by extending their range of application. Sometimes, these shifts create metaphors, then the metaphorical use of the words often leads to new meanings. Semantic shifts can be seen in computer technology. The terms 'mouse' or 'cookie' are but two examples. In mathematics, there are 'kissing circles' (refer to Figure 5); that is, circles that are placed tangential (= kissing) to a given circle (Schwartzman, 1994).

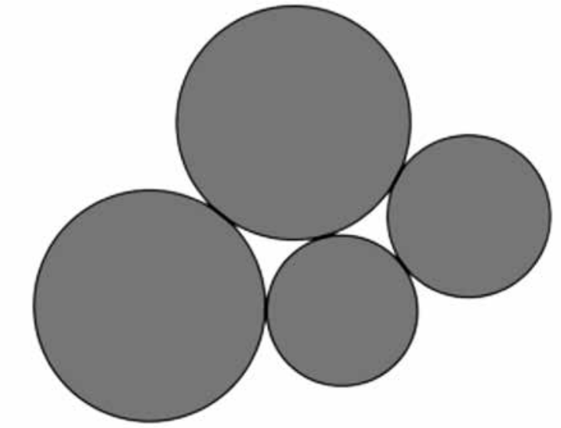

Figure 5. Kissing circles.

While this semantic link provides assistance to meaning, it can also provide difficulties for students learning mathematics, and for second language learners. For example, a right-angled triangle is one that has a 90-degree angle. This then suggests to second language learners that there may also be a left angled triangle. Durkin and Shire (1991) suggests words such as ‘leaves’, ‘product’, ‘table’, ‘high’ and ‘big’ have more than one denotative meaning: a basic everyday meaning, and a specialised meaning in mathematics, which may have implications for understanding. For example, they suggest that the word ‘make’ in the sentence '*Two and two make four*' can be misinterpreted by using its everyday meaning as in the sentence *'Mum and John make cakes'*. (p.75). While the use of ordinary language in mathematics is a powerful tool for understanding the development of understanding, and for communication, the overuse of the ordinary language by transferring not only the connotation of meaning of ordinary words but also the pragmatics, may result in improper applications in mathematics (Ferrari, 1999). Introducing the word ‘make’ into the mathematics register, may assist meaning for some, but simply confuse others. Hence in the teaching of mathematics, teachers have to be careful in the introduction of everyday words to explain mathematical concepts.

Teachers should be aware of the subtle differences in language. In some instances words used in a mathematics classroom may have altered meaning and grammatical function. Adams, Thangata and King (2005) suggest that teachers need to support students to use technical language when talking about concepts, and encourage students to make the connections between everyday meanings and the mathematical ones such as function, derive, mean, rational, or root. They also suggest teachers ensure there is time for students to “talk about mathematics as they solve problems, encouraging them to articulate patterns and generalisations” (p. 446).

As students move into more abstract mathematics, the use of technical language will increase and further borrowing of words will be encountered. Aldrich (2014) offers an example in topology with the statement: "A compact Hausdorff space is normal”. All the words, apart from Hausdorff, are everyday words,

> ...yet only two words have their everyday meaning, ‘a’ and ‘is’. The rest are technical terms: the everyday words ‘compact’ and ‘normal’ have been given mathematical meanings, while HAUSDORFF SPACE is an expression concocted by mathematicians. (Aldrich, 2014)

Topology offers many such words: neighborhood, connected, complete, ordered, field, union, and intersection, to name but a few.

Concluding comments

There are many activities that can be incorporated in the classroom related to mathematical words. Teachers could ask students to compare mathematical words or phrases in other languages, and asking ESL students the mathematical words in their language can be a way of including them in conversations. Activities around these words can be incorporated into a lesson, project or homework activity. Other activities can focus on the mathematical words in English. For example, students could be asked to look up the words ‘square’ and ‘trapezium’ in various dictionaries (or online) and compare them. They will see that there are not unified definitions. Perhaps we are used to the idea that mathematics appears to be a very black and white subject, but it is good to suggest to students that it is not always so. A word such as ‘restaurant’ is a hard word to define. For example, does a restaurant have to be indoors or provide table service? The answer to this question helps to characterise the ‘restaurantness’ of an establishment. Restaurant is a somewhat fuzzy concept. People are usually comfortable with this uncertainty. So for a word to be understood and used it is not necessary to know a tightly defined meaning. (Leung, p.129). As a teacher you can explore the fuzziness of word meaning, even generalising and extending meaning from one instance to another. Learning vocabulary, particularly in terms of its associated concepts and linguistic properties, is an ongoing activity that can be fostered in the classroom.

Describing how new words are incorporated into the lexicon is often straightforward. However, the words exemplified in this article, may have been through single or multiple processes. The word googolplex came from googal, which was coined and then blended. The word ‘tangram’ in English is borrowed from the Chinese ‘t’ang’ and then the morpheme ‘gram’ is added. The multiple processes may also include the borrowing not only of words but of morphology. This was seen with the introduction of more suffix-type words in Chinese, which is seen as a borrowing from English. Explaining why a specific word is introduced over another is more complex. Some words are deliberately chosen, as often happens in mathematics, but even then the final choice of words appears random. For example, the concept of negative numbers was debated in the 15th century. The words privative, (‘those which deprive’), along with fictitious, absurd or defective all appeared to stand for the concept (Schwartzman, 1994), but ‘negative’ eventually became the standard word used together with its negative connotations.

Language is flexible, creative, and grammatical, and no less so in the mathematics register. The development of new words exemplifies the flexible properties of language. Language has a capacity to be open to new words in very creative ways, yet still conforms to the morphological constraints of the particular language. While different cultures may incorporate new words in different ways, the important point is that mathematical concepts and terms themselves are shared and language is the essential tool used to share and think about these concepts.

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