Lexical access, knowledge transfer and meaningful learning of scientific terminology via an etymological approach

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Abstract

This study aims to illustrate whether or not students of a second-year introductory Zoology course who were taught their course terminology using an etymological approach would show improved learning on a number of metrics of student performance. Undergraduate students of any academic discipline are challenged by the learning of its specialized language, especially in the terminology rich fields of scientific study. A common approach among students towards learning the terminology is via rote memorization, often with little success. Studies in language learning have shown that learning scaffolds that involve a morphological breakdown of new words into their morpheme units allows for improved lexical access, as well as greater knowledge retention and transfer abilities to other words in the same morpheme families. The scientific lexicon is mostly made up of root morphemes and is auto-descriptive, therefore, by using an etymological approach while learning new scientific terminology, there are two advantages over rote techniques: firstly to have a learning scaffold that may allow students to integrate unfamiliar terminology into their personal lexical repertoires and secondly, to have the ability to infer meaning of the terms' properties with respect to their scientific contexts. These contributions may constitute a more meaningful student learning experience than factual intake and regurgitation and also they are allowing for metacognitive processing and conceptual linkage to the structure and/or function properties of terminology in their specialized scientific disciplines. This study adds to the growing body of teacher-led instructional learning resources for specialized vocabulary components of effective specialized scientific language learning at the University undergraduate level.

Key words: Language; Scientific Terminology; Curriculum; Learning Scaffold; Metacognition; Latin; Ancient Greek.

Introduction

For undergraduate students enrolled in a specialized academic discipline, learning of entire lexicons of terms specific to each field can be a considerable challenge (Wellington & Osborne, 2001). This is especially true for disciplines in the life sciences, whose lexicons are particularly large and include many difficult conceptual notions for students to learn (Carpenter, 1956; Stanley & Stanley, 1986; Wandersee, 1988). Furthermore, much scientific terminology is unique, in that it is largely made up of word morphemes (base units of meaning and function: Henry, 1993) derived from two dead languages: Ancient Greek and Latin (Heinrich, 1992). Thus today, undergraduate students must not only deal with the immense magnitude of the glossaries, but are also challenged by the foreign-seeming nature of scientific terminology and the lack of word recognition. As there has been a marked decline in the teaching of classic Linguistics in western education systems, this is a far cry from the situation where these studies were pre-requisites for entry to most universities not long ago (Hogben, 1969; Sharp, 2005).

Learning large lexicons

When students are tasked with learning specialized terminology, the most common approach is rote memorization (Pines & West, 1986; Mayer, 2002), sometimes with the use of making cognitive associations, such as using mnemonics or concept maps, which have been shown to improve word retention over rote memorization (Posner, 1996; Briscoe & LaMaster, 1991; Brahler & Walker, 2008). However, only true understanding can lead to long-term memory, retrieval and transfer of that knowledge (Carpenter, 1956; Pines & West, 1986; Wandersee, 1988; Chamot, 2004).

Furthermore, while rote memorization of terminology may allow for subsequent retrieval of the knowledge, it limits the student's ability to transfer that knowledge to new situations (Chamot, 2004). Students that learn by memorization are restrained to lower order cognitive processes, such as remembering and understanding and do not use higher level ones that permit them to apply, analyse and evaluate that information (Anderson & Krathwohl, 2001). Therefore, the goal of a science student learning a discipline's specialized terminology should ultimately be to be able to bridge the words from the domain of factual knowledge with that of a conceptual one, ready for application, analysis or evaluation.

Metacognition & language learning

The ability to acknowledge, recognize and critically assess one's thinking and learning patterns, a process known as metacognition, allows students to independently develop a temporary but appropriate learning scaffold for achieving understanding when encountering new unfamiliar situations (Flavell, 1979; Bruer, 1993; Chamot, 2004; Goh, 2008; Rahimi and Abedi, 2015). The aforementioned higher-level cognitive processes are fundamental to one's ability to undertake metacognitive learning. Studies have shown that metacognition plays an important role in language acquisition, oral and reading comprehension, as well as self-instruction in young children and adolescents (Flavell, 1979; Rahimi & Abedi, 2015). Before a word can be recognized and understood by students, it must first be registered cognitively in such a way that it is matched with their pre-existing word cache and then stored in their long-term lexicon (Rubenstein et al., 1970; Taft, 1979; Yap et al., 2008; Hawk et al., 2009; Rabovsky, et al., 2012). One metacognitive process by which language students are able to monitor and assess

their personal knowledge and learning is through an orthographic representation of the word via its morphological deconstruction (Yap and Balota, 2009).

A mechanism of word recognition when learning a new language proposes that information on the new term obtained from auditory (spoken), visual (orthographical) and semantic (contextual) sources are cognitively combined, acting to increase the levels of familiarity until a threshold of word recognition occurs (Morton, 1969; Balota et al., 2004; Yap et al., 2008; Santos et al., 2011). During an orthographic breakdown of unfamiliar words, knowledge of the internal morphological structure of the term increases the lexical access during learning (Taft, 1979; Carlisle, 2010) and the access code to new words, particularly polysyllabic ones appears to be in the root morpheme, once stripped of its affixes (Taft, 1985). Additionally, prior exposure to root morphemes subsequently improves the ability to recognize unfamiliar words derived from the same root (Murrell & Morton, 1974; Pexman et al., 2008) and children with an awareness of the morphological structure of words have demonstrated better vocabulary knowledge (Carlisle & Fleming, 2003) and reading comprehension (Carlisle, 2000). Morphological awareness has also been shown to improve lexical processing of written words in adults (Marslen-Wilson, et al., 1994).

The structure of scientific terminology

In addition to the aforementioned processes associated with generalized language learning, some features of the technical language of Science are that it is as descriptive as it is functional (Hogben, 1969; Sutton, 1992; Hand & Prain, 2006; Rector, et al., 2013), generally made up of a lexicon of morphemes, composed principally of Greek and Latin root units ascribed with various affixes (Fang, 2006). Furthermore, the polymorphemic elements of scientific terminology interact in such a way as to give internal structure to the term's meaning (Tyler & Nagy, 1990). For example, the term photosynthesis, composed of the morphemes *photo-* (from Gk. *phôs/photós* = light) and of *–synthesis* (from Gk. *syn + tithénai* = together + put), literally means 'put together with light'. Therefore, reading scientific terminology via an orthographic breakdown of the morphemic roots provides an inferred understanding of the structural and/or functional meaning of the term (creating sugars from light energy, in this example). This Ancient Greek and Latin-based internally-referential nature of technical scientific terminology may date back to Guyton de Morveau's memoirs (1781), detailing the principles for chemical nomenclature. He insisted that names should be of a descriptive nature and that the denominations should be composed of dead languages, thus avoiding colloquial ambiguities, as well as providing insight into the meaning of the word (Hogben, 1969). This reciprocal nature of scientific terminology reinforces the importance of recognizing the orthographic construction of terms from scientific lexicons in the learning of a new scientific discipline: a true understanding of the language of science can give insight into the scientific paradigm being studied (Wandersee, 1988; Locke, 1992; Hand & Prain, 2006).

Meaningful learning & knowledge transfer

Whereas, the goal of science educators in teaching scientific terminology to students may be to promote more *meaningful learning*, in that the students' knowledge of terminology may allow for them to not just recall the factual information at a later time (*retention*), but to also make sense of it and to use the recalled knowledge in a new situation (*transfer:* Mayer, 2002). Using word analysis as a learning strategy in a terminology-rich branch of science may allow students

to employ their general orthographic knowledge to break down unfamiliar polysyllabic terms into their potentially familiar morphemes (Henry, 1993). This in turn would allow for lexical access of the new term into the students' repertoires, as well as develop the ability to subsequently apply the knowledge to higher-level cognitive processes, such as a contextual analysis, application or evaluation of the scientific terms. The higher-level understanding of the terms would make it a deeper, *procedural* form of memory, involving skilled cognitive performance, rather than a shallower *declarative* one, involving a simple retention of facts that are more rapidly lost over time (Schmeck, et al., 1977; Cohen, 1991; Nosratinia, et al., 2014).

The Greco-Roman roots used in the technical languages of Science have allowed scientists to communicate for centuries, due to the past universality of those spoken or written tongues (Smith, et al., 2007). However, the intuitive link between a term's name and its meaning may have become lost on today's young scientists, due to the decline in teaching classical Linguistics in recent times (Drury, et al., 2002). Admittedly, this approach to understanding the structure/function information held within the nomenclature of scientific terminology is not new: my own previous professors as well as my current colleagues of the baby-boomer generation have suggested that it is how they were taught scientific terminology and the terms' etymologies are often included in contemporary textbook glossaries. However, the skill of etymologically-based word recognition appears to have skipped a generation or two in today's students that have never received any formal training in Latin and Ancient Greek. Nevertheless, the purpose of this study is to demonstrate that contemporary students in biological sciences may be capable of learning unfamiliar terminology despite their deficiency in classical Linguistics training, by using an orthographic breakdown, which may facilitate their learning experience, and improve word retention and knowledge transfer.

Pedagogical Application

I have taught a compulsory, 2nd year introductory Zoology course in the Department of Biology at the University of Ottawa in Canada (BIO2535) seven times since 2007 at the time of publication, known to the students as being a particularly terminology-rich course. Students have repeatedly stated that they find it difficult to retain the hundreds of words for structural terms, functions, processes and conceptual notions in the course lexicon. Subsequently, I have begun to emphasize word deconstruction and morpheme recognition using a learning strategy that I call 'The Etymological Approach to the Learning of Biological Terminology' [EALBT]. The objective is to aid students to incorporate new words into their personal lexicons by matching root morphemes to those already existing in their repertoires and making inferences about the terms' meanings from their etymologies.

In order to illustrate this process of etymological analysis, consider the following: during the course section on the evolution of vertebrates, we discuss two groups of bony fish, including the Class *Sarcopterygii*, whose name means little to most students of Biology. However, they can learn through morpheme deconstruction into its three orthographic units of *Sarco + pteryg + ii*, that it is a word made up of mostly familiar parts and can then go about attempting to match them with ones already in their stored lexical repertoires. A quick class discussion with the goal of soliciting other words with the same root morphemes usually yields such examples as *sarcophagus* (a 'flesh-eating' chamber), or *sarcomere* (a 'tissue-part'), as well as *helicopter* ('helix or spinning-wing') and *Pterodactyl* (a Genus of the extinct flying

reptiles with 'winged fingers'). Once this discussion is accompanied by an explanation that the *–ii* suffix is the plural in Latin for *–ius*, meaning "pertaining to, derived from", the students may have immediate lexical access to the term, as well as its contextual relevance to the field of study. The main ecological significance of the *Sarcopterygii* (Gk. *sárx/sarkós* + *ptéryx/ptérygos*: the fish with "fleshy wings/fins") is their evolutionary relationship to the fleshy-finned, air-breathing fishy ancestors of the modern day Amphibia, whose articulated limbs facilitated the colonization of terrestrial ecosystems (Ahlberg & Milner, 1994). The form and function link in the sarcopterygian orthographic breakdown therefore acts to reinforce the students' understanding that the fleshy-fins were an evolutionary adaptation that separated them taxonomically from their water-dwelling cousins, the *Actinopterygii* (Gk. *aktís/aktînos* + *ptéryx/ptérygos*: the "spiny-finned" fish).

Thus, the Etymological Approach is consistent with the generative model of cognitive learning meant to improve educational experiences by creating perceptions and meaning that are consistent with prior learning (Wittrock, 1974; Veenman, et al., 2006; Goh, 2008). Once lexical access for the term *Sarcopterygii* has been achieved by students, they may be primed for future morpheme recognition in such words as *Diptera* (flies, the 'two-winged' insects) or *pterophytes* (fern plants with wing-like fronds), for example.

Using the Etymological Approach while learning the morphometric languages of Science may therefore provide students with two tangible benefits over rote memorization: it may put in place a learning scaffold that allows students to decipher unfamiliar terms, as well as providing a link to the structural and/or functional properties of the term as it relates to the study of its scientific field. This form of learning of the terminology that is accompanied by an assessment of its meaning in relation to other known concepts (contextualization) provides a more fundamental form of learning (Miller, et al., 2002) and students are better prepared to engage in the ultimate goals of scientific literacy, to apply their knowledge of the language to their own endeavours of Science. The Etymological Approach may facilitate this more meaningful form of language learning.

In order to test the effectiveness of the Etymological Approach as a learning tool for students, I measured self-reported process indicators of student learning, due to the logistical and ethical challenges associated with presenting the technique to one half of the class, while withholding it from the other half to be used as a control.

Process indicators are measures of empirically-based principles and practices that are correlated with student learning, which in turn inform our assessment of teaching effectiveness (Angelo, 1996). Originally developed due to political pressure on colleges and universities for increased accountability and productivity (Kuh et al., 1997), process indicators are now commonly and confidently used as proxies for achievement test results (Pike, 1995), as they are easy and cheap to administer and they have been shown to correlate with good practice indicators known to improve the student learning experience, such as student-student interaction and active learning (Pike, 1996; Kuh et al., 1997). Well-formulated process indicators that show high correspondence between the content of the criterion variable and the proxy indicator, reveal correlations with good practice that are positive, significant educationally and statistically, as well as dependent and consistent across disciplines and institution types (Laing et al., 1987; Pike, 1995; Kuh et al., 1997).

I used an anonymous online poll (using www.surveymonkey.com) in order to assess the use and the learning potential of the 'Etymological Approach to the Learning of Biological Terminology' after one semester, and asked my outgoing classes in 2011 and 2012 to evaluate the following statements:

- I used the Etymological Approach during my learning of terminology for the course BIO2535
- And that compared to not using it, the use of the Etymological Approach while learning the course terminology:
- increased my ability to undertake independent learning
- improved my understanding of the course requirements
- allowed for a better management of my study time
- allowed for a diversity of learning styles among the students

The first of these questions was meant to assess whether or not the students had actually used the Etymological Approach as a learning tool for accessing the course lexicon and, for those students who indicated use of the technique, the following questions were meant to assess various components of improved learning potential derived from its use. These popular process indicators, based on the '7 Principles for Good Practice in Undergraduate Education' (Chickering & Gamson, 1987), rest upon the notion that active and meaningful student learning is improved upon when faculty and students devote more time to activities associated with the principles (Kuh & Vesper, 1997).

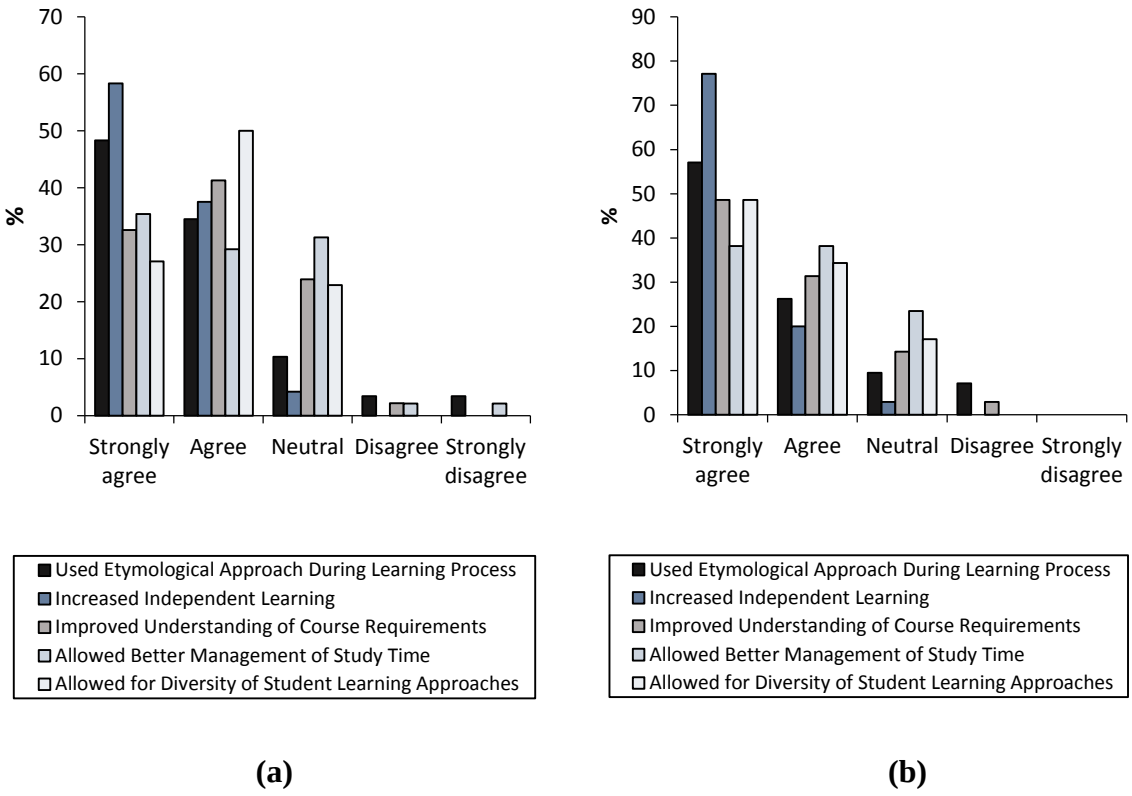
Survey findings

The response rate to the survey was 80.6 and 52.5% in 2011 and 2012 (58/72 and 42/80 students enrolled), respectively. The results are presented in Figures 1 (a), which is the representation of the *percent responses in each category of agreement from outgoing students of BIO2535 in 2011, collated from anonymous online assessments of their use of the Etymological Approach during the learning of course terminology, as well as their perceived effects of using the techniques on improving their learning experience and* (b), which is the representation of the *Percent responses in each category of agreement from outgoing students of BIO2535 in 2012, collated from anonymous online assessments of their use of the Etymological Approach during the learning of course terminology, as well as their perceived effects of using the techniques on improving their learning experience.*

In both years, over 80% of student respondents indicated that they had actively used the Etymological Approach as a learning tool for accessing the course's terminology. Of those students who used the technique, the vast majority indicated that it helped to improve various aspects of their learning experience, in terms of their ability to learn independently (95.8 and 97.1% responded positively in 2011 and 2012, respectively), their understanding of course requirements (73.9 and 80% in agreement ibid), their management of study time (64.6 and 76.4% in agreement ibid) and that the technique accommodated a diversity of learning styles among students (77.1 and 82.9% in agreement ibid).

Student testimonials

Additionally, many students reported anonymously through written statements during the official course evaluation that they appreciated how the Etymological Approach to Learning



(a) **(b)**

Figure 1. (a) *Percent responses from outgoing students of BIO2535 in 2011,* (b) *Percent responses from outgoing students of BIO2535 in 2012.*

Biological Terminology [EALBT] had provided them with a new and effective learning tool, see a few of the testimonials below from past students in the BIO2535 course as examples (*including translations to English from French where needed*):

> "Moreover, your approach to scientific vocabulary using etymology has greatly influenced not only the way I study science, but also the way I approach new fields."
>
> "Very appropriate! It [the EALBT] provides an easy solution to the problem of trying to remember terminology and what it means."
>
> "[the EALBT was] Useful for better understanding of course content."
>
> "Très utile, cela m'a vraiment aidé dans mes études. (*Very useful, it really helped me in my studies.*)"
>
> "J'ai appris l'étymologie des mots comme vous l'enseignez et je n'ai jamais eu autant de facilité à me souvenir des concepts et des mots-clés qui s'y rapportent. Merci! (*I learned the etymology of the terms like you taught us to and I have never found it so easy to remember the concepts and the key-words that describe them. Thanks!*)"

> "L'enseignement de Dr. Brown est stimulant. J'aime son approche étymologique dans ce cours. C'est très utile. (*Dr. Brown's teaching is stimulating. I like his etymological approach in this course. It is very helpful*.)"

> "L'approche et l'emphase sur l'étymologie des mots est une bonne manière à faciliter la compréhension. (*The approach and emphasis on the etymology of words is a good way to improve understanding*.)"

Discussion

Students in a 2nd year Zoology course indicated that the use of the 'Etymological Approach to the Learning of Biological Terminology' improved their learning experience, as suggested by self-reported process indicators that assess undergraduate learning (Laing et al., 1987; Pike, 1996; Kuh, Pace & Vesper, 1997) and from anonymous written testimonials. The most pronounced effect was in their ability to learn independently, confirming the usefulness of the technique as a learning scaffold and knowledge transfer tool while learning unfamiliar words, wherein the respondents were nearly unanimous in favour of this benefit (Figures. 1 (a) & (b)).

In this study, the use of an 'Etymological Approach to the Learning of Biological Terminology' has shown that it may provide students with a metacognitive learning scaffold for dissecting unfamiliar terms, matching the root morphemes to those in their personal lexicons and inferring structure/function aspects of the term's meaning, all while allowing for a monitoring and confirmation of the learning process by reciprocally matching the terms' etymologies with their meanings (Bruer, 1993; Goh, 2008). This more functional understanding of new concepts and terminology through the use of the Etymological Approach may lead to a greater retention in the students' lexicons, as once students have developed their own conceptualization of the terms beyond integration via rote memorization techniques, they may achieve a more *meaningful* understanding (Carpenter, 1956; Pines & West, 1986; Haag & Stern, 2003). Additionally, this form of metacognitive processing can improve learning because it allows students to assess their own personal learning progress, as well as adding to a diversity of learning scaffolds that can support the understanding of the material integration process, which in turn allows students to develop a larger inventory of learning strategies (Wenden, 1987). A similar instructional approach was taken towards medical students in introductory anatomy courses with similar results of enhanced learning experiences and enjoyment during learning, as expressed by the students (Smith, et al., 2007).

The Etymological Approach favours language learning, as it allows access to information related both to the morphological structure of the words, as well as contextual information inferred from the self-referential nature of the scientific terms' construction. Furthermore, as studies in language learning have shown, the recognition of root morphemes from previously stored lexicons allows language students the use of the same cognitive access code as the logged one and facilitate learning (Taft, 1985), so student brains may already be wired to optimize etymological breakdowns of unfamiliar terms.

It must be pointed out that the instruction of the Etymological Approach in this particular pedagogical application was with a Francophone audience, due to the bilingual nature of the University of Ottawa (English and French). It has been suggested that the speakers of

Romance languages may be at an advantage during morphological breakdowns of polymorphemic terms from Ancient Greek or Latin origin (Henry, 1993), over those speakers of languages that have historically borrowed from a much greater diversity of sources, such as the polyglottal ancestry of modern English, which includes Celtic, Anglo-Saxon, Nordic, Norman French and other languages as having made important contributions (Baugh & Cable, 1993). For this reason, many technical or specialized terms in Romance languages, such as French, have root morphemes that are homologous with the classics (Cohen, 1967), which is not always the case in English.

For example, when learning about arthropod reproduction in BIO2535, we discuss an egg-containing case often laid by female mantids and roaches, known as the *ootheca*, which has root morphemes that are inherently more accessible to Francophones than to Anglophones. Let us illustrate using the Etymological Approach: the root morphemes are oo- (Latin *ōvum* or Greek *ōon* = 'egg') and –theca (Greek *thḗkē* = 'box, chest, place to put something'), two units with direct derivations in contemporary French in *oeuf* and *-thèque*, as in *bibliothèque* or *discothèque*, not so for egg and library or nightclub, respectively, in English. The multi-lingual sources of English zoological terms can also be seen in their nomenclature for animals that are found both in the farm yards and on the dining room table, such as the retention of Germanic words used by Saxon farmers for the livestock names (cow, sheep, pig) and referral to the language of the Norman French Lords when we serve it up on our plates (beef, mutton, pork [*fr*: boeuf, mouton, porc, respectively]; cf. Nagy & Townshend, 2012). Thus, speakers of Romance languages may indeed have a *priori* advantages when it comes to the recognition root morphemes from Ancient Greek and Latin, due to a lack of distraction from other-sourced synonymous morphemes available in their own dialects.

Conclusion

Using orthographic deconstruction processes, such as the Etymological Approach, during the learning of scientific terminology may provide students with an independent learning tool, empower them with an ability to think critically and to transfer that knowledge to new learning situations, to provide a perspective on the structure/function properties of the new terminology, as well as to enable them to process lexical terminology at high cognitive levels. This study adds to the growing body of literature that demonstrates effective instructor-led learning scaffolds for domain-specific academic language at the University undergraduate level (Drury, et al., 2002; Miller et al., 2002; Smith, et al., 2007; Brahler & Walker, 2008; Lidbury and Zhang, 2008; Snow, 2010; Nagy & Townshend, 2012; Rector, et al., 2013). Future studies will explore the nature of a *priori* lexical access to Greco-Roman scientific terminology inherent to students hailing from Anglophone vs. Francophone linguistic backgrounds.

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