Linking Phrases for Concept Mapping in Introductory College Biology

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Abstract

Concept maps can be used in undergraduate biology as ways to visually communicate the relationships among things and events. One strength of concept mapping is that there is not just a single, correct way to compose one, given a list of particular concepts. Nevertheless there seem to be associations among ideas that are expressed frequently while teaching biology. For example, hierarchical relationships among structures and steps within processes are two common kinds of relationships that students encounter regularly. Based on our own classroom experiences and surveys of concepts appearing in two popular textbooks, we provide here a resource for composing propositions within biological concept maps. This list of more than 50 linking words and phrases is appropriate for freshman biology but can be adapted for use in more advanced courses.

Keywords: Mind maps, college science education, logical relationships

Introduction

The types of courses taken by a first-year undergraduate are usually formal introductions to particular scholarly disciplines. Success in such courses is required to then proceed to more advanced courses within that particular major field of study. However, these courses can act as veritable academic minefields to students, and are often referred to as gatekeeper or weeding-out courses because they frequently result in students doing poorly (and thus requiring a repeat term in the course), switching majors, or withdrawing from higher education altogether.

The issue of gatekeeper courses is especially acute for STEM majors. Whether the time spent until entry into a STEM career is referred to as a pathway, pipeline (Shaw et al., 2012; Allen-Ramdial & Campbell, 2014; Miller & Wai, 2015), or other metaphor, such experience involves a variety of factors that can either retain or repel students from the discipline. In some cases lack of success in an introductory STEM course (including required STEM courses outside of one's own STEM major) could determine whether a student continues to pursue any STEM career whatsoever. Decisions to abandon a STEM major may thus be based on the perceived rigidity of curricula and difficulty of courses within it. In other words, the timing and sequence of courses within a degree program do not allow a student to graduate "on time" if he fails any one particular course. (For the sake of brevity, we will not address here what constitutes an appropriate amount of time to complete degree requirements.) Another, related factor that may enter a student's decision-making process about whether to pursue a STEM degree has to do with what has been called the "push-pull" of majors. That is, majoring in a STEM discipline can be perceived as more difficult, less interesting, or otherwise less rewarding than majoring in a non-STEM discipline. The connection between introductory courses and the push-pull of majors was highlighted by Chambliss and Takacs (2014), who observed that a student's experience with her first professor in an academic discipline (e.g., an instructor of an introductory course) had a notable effect on whether that student decided to stay within that major.

The high vocabulary load of introductory biology courses may be a barrier to student success and may, in turn, have several contributing factors. One has to do with choices by individual professors to include more vocabulary than is absolutely necessary to attain their teaching goals and their students' concordant learning outcomes. Instructors' choices, in turn, may be driven by textbooks and their publishers' decisions to increase the amount of included jargon over time, to achieve a sense of up-to-date rigor. Biology's "terminology problem" does not seem to be waning and Wandersee (1988) observed that the field's ongoing proliferation of acronyms, terminology incorporated from chemistry, polysyllabic words of Greek and Latin origins, terms with multiple conflicting meanings, and new terms coined by empirical researchers all contribute to overwhelming and stifling the interests of nascent biology students.

Wandersee (1988) cited both Ausubel (as Ausubel et al., 1978) and Novak (1977) in his recognition of the weakness of rote learning (verbatim memorization) of biological terminology, and advocated for careful selection by professors of the terminology to be learned meaningfully by their students. In contrast to rote learning, meaningful learning allows for future learning of related concepts such that they can be subsumed into an individual's extant framework of knowledge (Ausubel, 1963, 1968). Drawing upon the work of Ausubel (1963, 1968), the development of concept maps (as described by Novak, 2010) was firmly intended to result in meaningful learning. Associations among biological terminology, concept mapping, and meaningful learning have thus been recognized (Wandersee, 1988) for at least three decades.

Ultimately, satisfaction with and, presumably, success in a course seems dependent upon whether a student felt engaged by the professor. Student engagement takes on various forms, not only within the spatiotemporal confines of a particular course, but also across the college experience as a whole. Active learning (Freeman et al., 2014) and student engagement often mentioned in the same work, and it can be argued that "active" and "engaged" are synonymous (Chi & Wylie, 2014) or that active learning is the process through which student engagement occurs. Course-based undergraduate research experiences (CUREs; Bangera & Brownell, 2014) and flipped classrooms are examples of two popular strategies designed to increase student engagement and, in turn, student success. Another active learning strategy is concept mapping, which was originally developed by Novak in the 1970s (Novak & Cañas, 2008). In contrast to CUREs and flipped classrooms, which might be categorized types of course formats, concept mapping is a type of course activity that is compatible with almost any type of course format.

Concept maps are similar in design to figures such as mind maps and argument maps: all are ways to express relationships among ideas. Davies (2011) compared and contrasted the three, concluding that they indeed represent distinct communication strategies with each having advantages and disadvantages. Concept mapping, as envisioned by Novak (2010), involves creation of a network of concepts that together help answer a focus question, describe a more encompassing topic, or otherwise establish what a particular set of concepts have to do with one another. Within a concept map, a pair of concepts is joined by a linking word or linking phrase, such that a proposition is formed. Linking phrases are typically only one to five words in length so the whole proposition communicates, in a manner akin to telegraphic language, the relationship between the two concepts. Each proposition has polarity or directionality, indicated by an arrow that joins the two concepts and near which the linking phrase is written. This directionality can be critical to the meaning of a proposition. For example, it would be factually correct for a proposition to indicate that "toe is part of foot" but it would incorrect to state, in the opposite direction, that "foot is part of toe." Similarly, an incorrect proposition such as "ATP produces glycolysis" could be modified to instead correctly assert that "glycolysis produces ATP."

Concept maps are similar to outlines in summarizing larger bodies of text or knowledge. An outline uses features such as subordination and division to portray logical relationships among its components. In concept maps, subordination can also convey hierarchies of ideas. These relationships can also be rendered in even more revealing ways in a concept map with explicit cross-links that are not easily gleaned from an outline, since each concept in a concept map may have multiple arrows leading to and from it, forming multiple propositions, which collectively express a meaningful body of knowledge.

Each proposition has the form concept-linking phrase-concept. An experienced concept mapper is able to effectively form propositions using appropriate linking phrases, organize concepts in a hierarchical manner, and provide cross-links (i.e., form propositions connecting different "regions" of the concept map) among related concepts (Mintzes et al., 2011). Rote learning, argued Ausubel (1968) and Novak (2010), contrasts with the meaningful learning that concept mapping ideally represents. The former is what instructors should not encourage in their own classroom activities or assessments. Rote learning, however, is unfortunately the default strategy for many students. It often takes the form of memorizing definitions to vocabulary terms (i.e., concepts) without real demonstration of how such terms are related. Encouraging students to map a given set of concepts, either as a formative or summative assessment, allows them an opportunity to struggle with (and therefore meaningfully learn from) how to briefly and accurately express, in the telegraphic language of propositions, what they know about a biological topic.

Methods

We contend that concept mapping is a strategy appropriate for introductory college biology, among other types of courses, and that our included list of linking phrases is useful for potentially increasing rates of student success in such courses. This list (Table 1) was compiled through reflection upon our own teaching and research experiences in biology, and extracting from them the kinds of phrases and verbal collocations that we perceive to be used frequently. We also inspected the glossaries of two introductory textbooks that have national distribution (Russell et al., 2014; Urry et al., 2016). Each glossary entry's part of speech (e.g., noun, adjective) was determined. Percentages of nouns, verbs, and adjectives were then calculated to quantify the relative importance placed by textbook authors upon the different kinds of biological concepts (i.e., things, actions, descriptors) in their texts. These data, in turn, helped ensure that our linking phrases that would be appropriate for propositions incorporating common concepts from introductory college biology.

adjacent to analogous to	affected by approaches	always higher than approximates
argued for, against	as in	assume(s)
attracted by, to	become(s)	bound to
calculated by	cause(s)	characterized by, using
combines with	composed of	connected to
consists of	constant when	constrain(s)
contain(s)	contrasts with	converted to, via
cycles through	decreased during	derived from
determine(s)	develop(s) within	developed method(s) for, to
discovered	doesn't affect	enable(s)
enter(s)	equal to	equation for
evidence of	exclude(s)	exit(s)
expressed by	evolved in, into, during	for example, e.g., such as
forms	found in	function(s) in, to
has rate called	homologous to	in other words, i.e., that is
in units called	increases with	indicated by, with
influence(s)	inherited by	inhibit(s)
inversely proportional to	is absence of	is, are not same as
join(s) with	likely when	limited by
means flow of	measure(s)	modify(-ies)
needed for	negative when	never higher than
occurs before, after, during, until	opposite of	part(s) of
pass(es) through	perform(s)	persist(s) when
possess(es)	proceed(s) without	produce(s)
proportional to	quantify(-ies)	randomly change(s)
realized that	receive(s)	related to
repels	require(s)	result of
results in	rises exponentially with	rises non-linearly with
serves to	smaller than	special case of
split(s) into	stimulate(s)	stops if, when
stored as	strengthens	subset of
substrate(s) for	supported by, with	surround(s)
symbolize(s)	synonymous with, same as	transfer(s)
transported by, to, from	type of	undergo(es)

Table 1. Alphabetical list, in horizontal rows, of example linking phrases for use in biological concept maps. Included are phrases that occur commonly in introductory college biology. Note that some standalone words in the list can be linguistically changed into phrases and vice versa. For example, the word "stimulates" can be converted into the phrase "stimulated by." However such conversions should be used cautiously during construction of concept maps, as they can substantively change the meanings of propositions (e.g., "X stimulates Y" contradicts "X stimulated by Y").

Some standalone words in the list can be linguistically integrated into phrases and vice versa. For example, the word "stimulates" can be converted into the phrase "stimulated by." However such a change can inadvertently reverse the directionality of a proposition if not done judiciously (e.g., "X stimulates Y" does not hold the same meaning as "X stimulated by Y"). Thus the use or substitution of a particular preposition within a proposition can alter its meaning. Notice also the differences in meaning of "transported to" and "transported from." Given this linguistic flexibility of the 105 linking words and phrases provided in Table 1, we conjecture that many more can be easily derived from those given.

Discussion

Introductory undergraduate biology is rife with specialized vocabulary, and courses for similar audiences in chemistry, physics, and mathematics also rely on specialized vocabulary along with hosts of symbols, all of which can infiltrate introductory biology. Novak (2010) would consider all of these terms, symbols, and other ideas to be concepts, which can be learned by concept mapping. He described typical concepts as being either "things" or "events." In the context of biology, things include anatomical structures, famous biologists, techniques, theories, or types of molecules, whereas events might include biological processes like meiosis or speciation. (In a sense, biological processes are thus both "things" and "events.")

Interestingly, biological vocabulary seems to favor noun forms rather than verb forms (for example "photosynthesis" as opposed to "photosynthesize"). Even less emphasized in introductory biological vocabulary are adjectives (e.g., photosynthetic), though all of these parts of speech play critical roles in biological discourse. Our cursory analysis of two widely used introductory college textbooks (Russell et al., 2014; Urry et al., 2016) reveals that, in each case, less than 3% of glossary entries are adjectives. The remaining terms are almost exclusively nouns. We have not investigated, however, whether instructional emphasis on the noun, verb, or adjective form of a concept has a differential effect on learning introductory biological vocabulary.

In general concept maps can include any part of speech. However, given the proclivity for biological concepts to be emphasized as nouns, propositions within biological concept maps are likely to link either two nouns with a linking phrase (a noun-noun proposition), link a noun and an adjective (a noun-adjective proposition), or link a noun and a verb (a noun-verb proposition). Propositions involving other parts of speech (noun-adverb, adverb-adjective) are assumed to be even less frequent in biology. Thus the linking phrases listed here are probably most appropriate for propositions that include at least one concept that is a noun. Most contain either a verb or both a verb and preposition, since the object of a preposition is also a noun. The linking phrases presented here include many that are formatted to accommodate concepts that are either singular or plural nouns, to allow subject-verb agreement (for example, "affect[s]") within propositions.

Experts can relate concepts to one another in succinct ways that novices cannot. That is, novices sometimes struggle to express deep knowledge in the propositional format required for concept mapping. For example, if a student were asked to link the biological terms cristae and mitochondria, he might respond by formulating a proposition that reads "cristae relate to mitochondria." While this proposition is true, it would be more meaningful if it also indicated how exactly cristae are related to mitochondria. Thus, propositions asserting that "cristae part of mitochondria" or "cristae found in mitochondria" are true statements that simultaneously describe the conceptual (here, structural or spatial) relationships between cristae and mitochondria. The linking words or linking phrases provided herein are some of many that students can use in their own concept maps. This list includes linking phrases that describe quantitative, structural, temporal, and other kinds of relationships that exist among the biological concepts commonly taught in introductory biology. As students become more confident in the mechanics of concept mapping and become more experienced using linking phrases that convey meaningful relationships (such as those supplied here), they can begin to craft their own linking phrases that also do so. In the absence of such examples, a concept mapper may remain as a novice, composing only vague (even if true) propositions. An instructor might interpret such hardship to mean that the student has not grasped the mechanics of concept mapping, does not understand the relationships among particular concepts, or both.

Linking phrases, as components of propositions, help elucidate the "who, what, where, when, why, and how" of biological ideas and interrelationships among them. While each concept can represent a standalone thing or event, the linking phrase better places it in context. Linking phrases hold explanatory power for describing the timing, duration, location, function, cause, effect, or mechanism of an event. They can also be crafted to specify whose ideas influenced or conflicted with whose, what characterizes particular structures or groups of organisms, and how certain data are collected. In short, propositions constructed with appropriate linking phrases can express the kinds of ideas that are commonplace in introductory college biology. Individuals often possess more information than they can easily express. The list of linking phrases provided here may help students and faculty unlock this tacit knowledge (Polanyi, 1966) so that it can be codified, refined, or preserved using concept maps.

As undergraduate biological education continues to undergo reform, and as instructors continue to find value in it for teaching or assessment, concept mapping may be used more extensively. It can be noted, for instance, that concept mapping remains compatible with all of the biological core concepts (evolution; structure and function; information flow, exchange, and storage; pathways and transformations of energy and matter; and systems) and core competencies (ability to apply the process of science, use quantitative reasoning, use modeling and simulation, tap into the interdisciplinary nature of science, communicate and collaborate with other disciplines, and understand the relationship between science and society) promulgated by Vision and Change: A Call to Action (AAAS, 2011) . As also mentioned above, concept mapping can be integrated into almost any kind of biology course format, including online courses, hybrid courses, CUREs, and flipped classrooms.

Corpus-driven analyses (sensu Biber, 2009) of introductory biology textbooks, edited volumes, and journal articles may provide quantitative insight into the kinds of phrases that describe the logical relationships among natural phenomena (i.e., biological concepts). Through identifying common patterns of how professional biologists communicate ideas to one another, we may better understand how to effectively explain new ideas to our own students. By modeling and working with concise, factually correct propositions in concept maps, we can train our students to maximize their explanatory power in the academic discourse of biology.

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