Perspective

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Conjunctional Concepts: The Conceptual Teaching Technique in Biology Classes

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Conceptual teaching relies on concepts in conjunction with a bigger conceptual category (or categories). Revealing and using conceptual conjunctions in the science classroom means teaching conceptually. To make conceptual teaching more accessible to biology instructors, a three-concept model was described to be used during a lecture. This model has allowed the author to develop a relatively simple method that starts with an active concept or concepts, then introduces conjunctional and supporting concepts to relate the content to other concepts and relevant real-world applications. This method is intended to help instructors in preparing to teach biological concepts conceptually, in order to foster an enduring understanding of biological principles in their students.

KEYWORDS three-concept teaching model, conceptual teaching, active concept, conjunctional concept, supporting concept

INTRODUCTION

Fifty-five percent of science, technology, engineering, and mathematics (STEM) classroom interactions in North American universities still consist primarily of conventional lecturing (1). This approach to education often leads to a regurgitation of disconnected facts, which causes students to memorize definitions while lacking an understanding of the overall concepts. Thus, teachers can lose the joy of teaching, and students can become deprived of the joy of learning.

After teaching in both high schools and universities, it has become apparent to me that instructors should reveal connections among concepts and help students to organize information into logical mental structures, rather than presenting them as clusters or fragments while simply following the course syllabus. There is an increasing need to identify well-structured conceptual frameworks of teaching content in biology classes at different levels of education. This aim finds support among professional organizations (2, 3) and curriculum-design authors (4–6).

Conceptual teaching is a pedagogical approach that focuses on related or interrelated concepts, not just the presentation of isolated bits of information. In this context, concepts are categories that contain smaller facts or ideas in conjunction with larger categories. To lecture in a conceptual manner, the instructor must have a conceptual vison of the topic. Conceptual vision is the ability to see and identify patterns in natural phenomena and articulate meaningful relationships between and among them. In the science classroom, an instructor should be encouraged to reveal those relationships using an active concept, a topic under consideration. Conceptual teaching uses the presentation of those interrelated patterns to the best of a teacher's ability to ignite and drive students' interest and create enduring understanding of natural phenomena.

Despite recent publications (7–11), not many educators are familiar with conceptual teaching. While the importance of conceptual teaching has long been established (12) and a number of books and papers have been published on the topic, the framework of this teaching method is rarely comprehensive to a vast majority of education practitioners. One of the reasons for this is a lack of clear structures and precise terminology in the guidelines. Teaching for conceptual understanding is a complex endeavor that many educators have strived for throughout their careers (8). Conceptual teaching tools, such as case studies, formative assessments, diagnostic tests, concept maps, and approximate analogies, and so on, are widely available and their use is encouraged, but the framework of this method is still unclear to most instructors. I learned this from numerous teaching observations and conference presentations—in fact, conceptual teaching is rare in classrooms, especially with novice instructors.

While ambitious science education reforms focus on the integration of related and interrelated concepts (3), techniques for achieving this goal are still vague and unclear. Therefore, this integration unfairly receives less attention among practitioners

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(13, 14), and teachers have been given limited guidance on how to integrate related and interrelated concepts into science instruction (15). Some papers sporadically appear on this topic (16–21), but all are focused on time-consuming activities such as laboratory exercises, research projects, and field investigations. There is a lack of publications on how to introduce conceptual teaching into lecture sections and turn traditional lectures into interactive student-centered lessons.

This paper attempts to share a basic framework that could be used during lectures in both K-12 and higher education to help educators design well-structured lesson plans based on the conjunctional concept technique that I have developed and utilized in a variety of biology classes for the last 15 years. Introducing conjunctional concepts in a STEM classroom not only leads to conceptual learning but often sparks student interest and makes them ask questions, often revealing interesting insights into the teaching topic. The proposed conjunctional conceptual technique is an engaging method for those who either prefer to be or have to be (due to structure/resources/student numbers) in a primary lecture-based format, where conjunctional concepts may become a bridge to student-centered interactions.

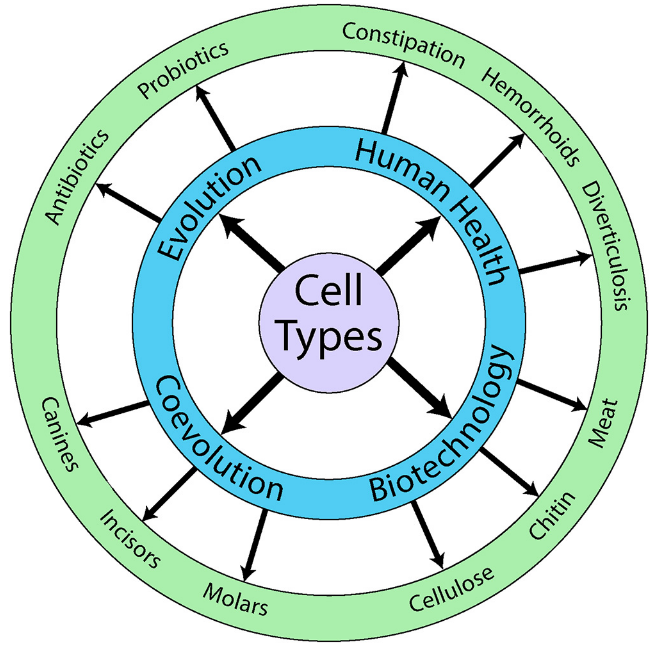

FIG 1. An example of the use of conjunctional concepts during a lecture on cell types. "Cell Types" is an active concept. "Human Health," "Biotechnology," "Evolution," and "Coevolution" are conjunctional concepts, branching out to supporting concepts such as "Antibiotics," "Cellulose," "Molars," and so on.

CONJUNCTIONAL CONCEPTS

Before introducing conjunctional and other concepts, it is important to define the word "concept" itself. A concept can be a word, such as "diffusion," "photosynthesis," or "biology." It can also be a phrase, such as "cellular respiration," "kinetic energy," or "atomic nucleus." A concept represents an abstract idea; it is the general idea of an object, process, theoretical definition, or category. The word "fork" could be considered a concept, since it represents the idea of a specialized instrument, a utensil with a defined function. Concepts are the building blocks for most of the cognitive capabilities we have (22).

A concept to an educator is like a cell to a living organism—it is the basic structural and functional unit of the educational process. There are various concepts. In social studies and cognitive science, there is a classification of concepts, but unfortunately, none of those can be applied to pedagogy. In my lesson plans, I identified the following three types of major structural concepts (Fig. 1 and 2):

(i) Active concept: a topic under classroom consideration or discussion.
(ii) Conjunctional concept: a concept that lies outside of the framework of the active concept but still relates to it.
(iii) Supporting concept: an example that helps to clarify the conjunctional concept.

The use of this three-concept model not only helps to makes course material more structured, more dynamic, and more memorable to the students but also makes connections within the material that students might never have thought existed. The differentiation among the concepts clarifies the framework of conceptual teaching and makes the method of conceptual teaching more comprehensible and accessible to science educators.

To be better understood, an active concept must be accompanied by a conjunctional concept(s). Before choosing a conjunctional concept(s) for the lecture, an instructors must determine the main focus of the active concept they have to convey to their students. For example, if the focus is science and society, the following conjunctional concepts could be at hand: human health, biotechnology, and evolution. If the active concept is the plant cell, and the instructor chooses human health as the conjunctional concept, the

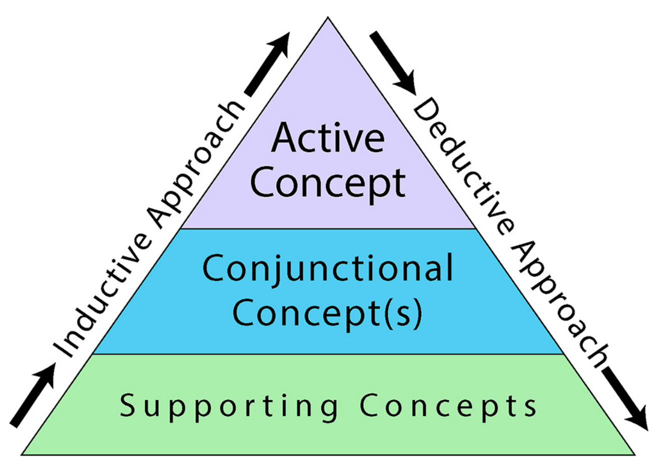

FIG 2. Three-concept model of the conjunctional concept teaching method.

TABLE 1
Some examples of conjunctional concepts incorporated into the lesson plan or lecture

Active concept	Main focus	Conjunctional concept(s)	Supporting concept(s)
Divisions of biology	Scientific language	Diversity of life forms	Animals, plants, fungi bacteria, etc.
		Professional specialization	Ornithology, ichthyology, entomology, biochemistry, etc.
Outer structure of eukaryotic cells	Environmental relationships	Coevolution	Herbivores: molar teeth
			Carnivores: canine teeth
			Omnivores: molars, canines, and incisors
Mitochondria	Human health	Genetics	Mitochondrial myopathies
		Sperm migration	Anatomy of a sperm cell/ATP production
Lysosomes	Human health	Genetics	Lysosomal diseases: Tay-Sachs disease, Hunter syndrome, Hurler disease
		Immunology	Phagocytosis
	Developmental biology	Morphogenesis in animals	Tail of a tadpole
		Embryology	Human fingers
Svedberg units	Interdisciplinary connections	Abstract algebra (useful deviation from the topic)	Closed system (11 + 3 = 2) (different way of thinking)
Cellular respiration	Toxicology	Poisons	Rotenone, arsenate, and cyanide

instructor might introduce students to the importance of dietary fiber, the cellulose from plant cell walls, in the human diet. The appropriate supportive concepts, in this case, would be such conditions of the gastrointestinal tract as constipation, hemorrhoids, and diverticulosis due to an insufficient amount of dietary fiber. From this, the instructor can explain that a lack of fruits and vegetables in one's diet can lead to colorectal cancer (23), as well as cancer of the small intestine (24). Thus, a lower-order-thinking learning outcome can lead to the development of a higher-order-thinking learning outcome. For example, compare the following two learning outcomes:

(i) Describe the physical characteristics of a plant cell wall.
(ii) Explain how diet choices may affect one's gastrointestinal health.

Indeed, the last learning outcome belongs to a higher Bloom's taxonomy level, compared to the first one. The first outcome involves recognizing or remembering facts without necessarily understanding the importance of plant cell walls in ecosystems and human health specifically. The second outcome allows students to reveal an important connection between the cellular structure of a plant and another living organism. Moreover, this outcome reinforces the first one because it reveals meaning that students can easily relate to.

Here is another example. To reveal the importance of studying organic material produced by organisms with various cell types (animal, plant, and fungal cells), instructors may introduce students to the conjunctional concept of biotechnology, with such supporting concepts as the industrial use of cellulose, chitin, and meat. Alternatively, while covering the outer structure of eukaryotic cells (animal, plant, and fungal cells), the instructor might also bring the students' attention to the animals' teeth, specifically those that eat plants (herbivores), meat (carnivores), and a mixture of both (omnivores). An active concept—the outer structure of eukaryotic cells, in this case—will be accompanied by an excellent example of the coevolution of living things (conjunctional concept), which at the same time will serve as a meaningful introduction of the supporting concept—animal tooth structure (molars, canines, and incisors) (Fig. 1 and Table 1). The different shapes of the teeth will demonstrate adaptation to a nutrient's availability and make connections between two seemingly unrelated topics that students might not have thought existed. Such outreach to the principle of coevolution brings student understanding of the living environment to an utterly new level and prepares them for the next unit, in which evolution is an active concept, not a conjunctional one.

Introducing conjunctional concepts into the classroom turns *teaching a concept* into *conceptual teaching* and thus becomes a fundamental part of this educational method. Active concepts should not stand alone in a science classroom. Students tend to remember and understand concepts when they see the meaning beyond the single frame of reference. Even if there is a textbook approved by the syllabus, the instructor might decide which conjunctional and supporting concepts to bring up for the classroom's consideration. This might depend on the instructor's field of expertise, updates to the scientific literature, and students' level of readiness.

BASIC STRUCTURE OF THE CONCEPTUAL LECTURE

Even though the theoretical framework described above seems to have a deductive nature—teaching from more general to more specific (top-down)—it could be inductive as well (bottom-up) (Fig. 2). After all, good teaching goes in both directions, and an instructor might start from supporting concepts and work all the way up to the active concept through the bridge of the conjunctional concept. As an example, a lecture with evolution as an active concept could introduce the example of antibiotic resistance. Not long ago, gonococci, a diverse group of bacteria and a causative agent of the sexually transmitted infection called gonorrhea—were susceptible to 55 different types of antibiotics. Currently, we have only one antibiotic that is barely working against this disease; it destroys the pathogens in some patients but is unable to do so in others (25). In a relatively short period of time, these microorganisms developed antibiotic resistance; antibiotics became a selective force in gonococcal evolution because—no matter how small species are—their traits are almost as diverse as the facial traits of the students sitting in the classroom before an instructor.

The paragraph above was a concise example of the inductive approach when using the conjunctional concept technique. Thus, the paragraph started with a supportive concept first (diversity within species); then, it introduced a conjunctional concept (antibiotic resistance in bacteria) and ended with the active concept (evolution).

While lecturing on the circulatory system, however, I prefer to use an inductive approach. First, I tell my students a story about a friend who had septicemia, i.e., blood poisoning, after sewing his own wound with a regular unsterile needle and thread. My emphasis is on the importance of the circulatory system and the great danger of not treating it properly. In this case, the conjunctional concept is society and health, or real-world experience. Real-world experiences, especially instructors' narratives of personal experience, are usually found to be quite interesting by students (26, 27).

A conjunctional concept can be a concept that was previously covered as an active concept or a concept that is to become an active concept in a later class period during the semester. In one instance, it might be a good reinforcement of previously covered topics, while in another instance, it might be a good introduction to the upcoming chapter. Making these connections helps to reinforce and review the course material. For example, while covering the skeletal system, it might be helpful to make connections with the lymphatic system and muscular system. When going over the integumentary system, it is important to talk about the peripheral nervous system, Hansen's disease, and infections caused by herpesviruses. This is because one of the functions of the integumentary system is sensory reception, and both of these pathogens interact with nerve endings. (*Mycobacterium leprae* replicates inside nerve cells and damages nerve endings, and many types of herpesviruses reside in the nerve endings).

When lecturing on infectious diseases, I would advise from time to time to mention concepts that an instructor particularly cherishes. Among them could be Koch's postulates, human body systems, characteristics of living things, mechanisms of homeostasis, the scientific method, and evolutionary adaptations. Building a table is a useful tool for organizing material for upcoming lectures or lessons (Table 1).

I like to conclude the semester with an introduction to controversies in science. This demonstrates that science is a constantly developing and self-correcting enterprise, and this allows students to bring up all sorts of concepts covered during the semester. Classroom discussions and student presentations could be a good way to review the course objectives, when students themselves should be able to use conjunctional concepts in order to support their own points of view (11, 28).

MODERN BIOLOGY TEXTBOOKS AND CONJUNCTIONAL CONCEPTS

In most college textbooks, conjunctional concepts are integrated within the chapters (29, 30), providing a variety of options for an instructor to choose from. However, those concepts usually are not specifically identified, and the instructor has to use his/her own judgment and philosophy for what to choose.

Some textbooks offer extra information in designated parts of the chapter, but there are fewer textbooks that identify conjunctional concepts in their chapters. For example, in Mader and Windelspecht's *Biology* (31), the end of each chapter refers to such concepts as "themes," which are as follows: (i) evolution, (ii) the nature of science, and (iii) biological systems. Each of these themes contain supporting concepts, which are also identified in their designated places. For example, the evolution theme contains such supporting concepts as metagenomics, carboniferous forests, the anatomy of speciation, and so on; the biological systems theme contains the Zika virus, drugs of abuse, urinalysis, and so on; and the nature of science theme contains "Microscopy Today," flu viruses, inbreeding in populations, and so on.

There is plenty of information available, but it is up to the instructor to decide what should be incorporated into their lectures and how this material can be used to build a lesson plan.

CONCLUSION

Besides making the covered material better structured and better prepared for conceptual teaching, the arrangement of teaching material into the three-concept teaching model makes topics covered in the classroom more intriguing, interactive, and meaningful. This is apparent from my students' comments, both on websites and in instructor evaluations by my students.

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