THINKING, TEACHING, AND LEARNING SCIENCE OUTSIDE THE BOXES

Reconsidering interdisciplinarity in science instruction

—— William F. McComas, Guest Editor ——

If Englishman Thomas Young (1773–1829) is known today, he is probably recognized only by students of physics or those with a passion for trivia, for Young is frequently called "the last person to know everything." In spite of competition from other polymaths, such as Aristotle, Erasmus, da Vinci, Leibniz, Kircher, Gauss, Diderot, Jefferson, and Asimov, one can certainly make the claim that Young is a strong contender for the title.

Young was a physician who devised a method for determining drug dosage in children and proposed a germ theory of disease. He was also a physicist who worked in optics, color vision, surface tension, and capillary action. Young performed the double slit experiment demonstrating the wave properties of light, investigated elasticity (think Young's modulus here), and defined energy in the modern sense. In addition, he spoke at least 10 languages, played a major role in deciphering Egyptian hieroglyphics, served on the Board of Longitude, and even worked out some of the mathematics of life insurance (Robinson 2006; Kline 1993).

While it can also be argued that he did not know *everything*—he seems not to have engaged in a broad study of the life sciences, many areas in the arts and humanities escaped his interest, and he did not work in the realm of Earth and space sciences—his range of knowledge is still inspiring. A close examination of his work shows a focus in physics and medicine. This degree of border crossing may have been responsible for some of his fundamental discoveries about color vision, as he had an intimate understanding of the structure of the eye and the physics of optics and light. For instance, this cross-disciplinary knowledge enabled Young to conclude that the retina had several discrete (rather than infinite) color receptors (Robinson 2006). The marriage of physics and medicine also permitted him to accurately describe the cause and visual implications of astigmatism—something he may not have been able to do if his range of experience was limited to just medicine or physics. It matters little whether or not Young was, in fact, the last man to know everything, but he was most certainly a Renaissance thinker whose knowledge crossed the now-common dividing lines between disciplines.

The disciplines

With the growth of the early universities, we saw the first formal segregation of human knowledge into disciplines. The medieval bachelor's degree required that students learn the "trivium" (grammar, logic, and rhetoric) as preparation for the "quadrivium" (music, geometry, arithmetic, and astronomy), which together comprised the liberal arts (Abelson 2007; Joseph 2002). For centuries, science grew alongside the arts and humanities at the hands of the *natural philosophers* (Ronan 1982). In the mid 1800s, the label changed to *scientist.* With increased specialization, even *scientist* was replaced with *chemist*, *biologist*, *geologist*, *astronomer,* and *physicist*.

As I write this essay, I look out on the beautiful campus of the University of Arkansas and can see Old Main, the stately first building that once housed the university. Peering back through time, one can imagine when members of the art department regularly crossed paths with those in literature; a mathematician would lunch with a biologist; and a chemist and physicist would sit across from each other in the single small library. Now my university, like so many others, has scores of huge buildings, many of which are designed and set aside for the exclusive use of those in a single discipline. As Becher and Trowler (2001) report, the notion of specialization has grown so strong that, at least in higher education, disciplines might best be called "academic tribes and territories" and studied through the lens of the cultural anthropologist as if they were foreign lands and peoples.

In both universities and K–12 schools, students leave one world and enter another as they attend classes in these discipline-specific domains. But how can students gain the experiences necessary to make discoveries—for personal satisfaction, for academic enlightenment, and perhaps even for the betterment of humankind—without educators who see the advantages of and can provide worthwhile experiences in such practice? In our age of hyper-reductionism, accompanied by an almost fortress-like mentality regarding the sanctity and value of disciplines, perhaps it is time to examine what it would be like to think and learn outside the boxes. It is very likely that the next important breakthrough in human understanding will come from those who, like Young, are able to straddle the lines between the discipline boxes.

Defining *interdisciplinarity*

At first glance, *interdisciplinarity* would seem relatively easy to define; it essentially means crossing the discipline boundaries between one field of study and another. However, this definition should be further refined by consulting Phenix (1964) for a definition of *discipline* itself. In his influential book *Realms of Meaning*, Phenix uses the concept of "ways of knowing" to help focus the definition. In his view, these ways of knowing include empirics (science), symbolics (mathematics), aesthetics (arts), ethics, synnoetics (literature), and synoptics (history). Therefore, it is more accurate to describe interdisciplinarity as the crossing between various ways of knowing or what some might call "schools of thought."

To reflect on the organization of disciplines in schools, consider the diagram provided in Figure 1 (p. 26), illustrating the various ways of knowing rendered as clusters of typical school subjects. These school subjects are organized into suites within a particular discipline such that physical science/physics, chemistry, Earth/space science, and biology are together within the discipline of science. The individual sciences, of course, have their own content, but science itself is a unique way of knowing with a number of overarching philosophical and procedural elements tying the individual subjects or disciplines together.

In examining Figure 1, consider the definition of *discipline* provided by Phenix and it soon becomes clear that in order to describe the educational implications of crossing boundaries, we should consider the use of a new descriptive term. To preserve the distinction made by Phenix, perhaps it would be best to call border jumping within a single way of knowing *intradisciplinarity* or *blended science,* as suggested by McComas and Wang (1998). Such a term better describes the kind of connections made within a discipline. For example, in a curriculum blending chemistry and biology we encounter a similar way of knowing, in spite of the unique content of biology and chemistry. In addition, the label *intradisciplinarity* also implies that it will be easier to design and promote lessons that link two sciences, for example, than to link more widely separated disciplines such as chemistry and literature.

Why interdisciplinary instruction?

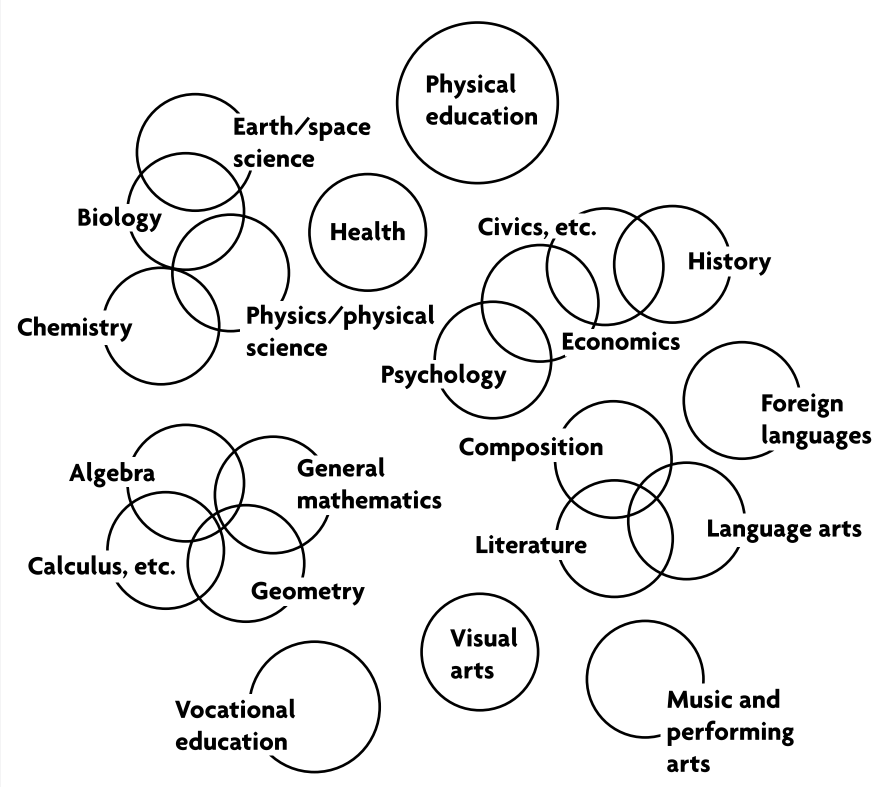
The rationales for curriculum integration are varied and represent the viewpoints of students, teachers, and society at large. Recently, a colleague and I reviewed the wide number of rationales recommending instructional integration and discovered four main clusters into which these rationales fall (McComas and Wang 1998): philosophical, psychological, pedagogical, and pragmatic domains. A review of more recent thoughts on the reasons to support interdisciplinary teaching reveals that a few justifications have been provided, but the basic categorization remains well substantiated.

From a philosophical perspective, it is clear that while nature presents a continuity of knowledge, humans have divided the world into chunks. Giving learners an opportunity to view knowledge in a fuller, more holistic, and, ultimately, more authentic fashion can be eye-opening, revealing, and intensely satisfying. Stephen Jay Gould, in his popular books, shows how effectively connections between literature, history, and evolutionary biology can enhance understanding in clever and enlightening ways.

The psychological justification for interdisciplinarity stems from the philosophical aspect; many students already have trouble seeing connections, and teaching the disciplines separately only increases the psychological distance between them. When the walls are already taken down through high-level intra- or interdisciplinary study, it is simply easier for students to see the areas where connections can be made. Furthermore, students can be engaged in a quest for understanding and application in real-world settings. As Bransford et al. (1990) point out, knowledge without apparent application may not be perceived as meaningful and, as such, may not transfer to other learning situations.

FIGURE 1

The current landscape of departments and subjects in typical secondary schools.



ADAPTED AND ENLARGED FROM SISKIN (2000)

Rationales can also be found within the pedagogical realm. Students may benefit from seeing the world in a less-constrained fashion; thus, teaching effectiveness is increased when students are permitted to explore in ways that have personal meaning. Also, the success that students feel as a result of their personal efforts can lead to enhanced engagement. In other words, if students are satisfied by what they can accomplish on their own, their independence as learners will increase. Teachers may be challenged when asked to move from a previous comfort zone, but doing so can be motivating for them as well. Teachers in interdisciplinary settings will likely see connections they might not have perceived previously and may consider instruction different as a result. Therefore, a rationale of empowerment is associated with interdisciplinary instruction.

Finally, there is the practical perspective, which to some extent unites the three previous justifications for teaching outside of the traditional boxes. Associated with almost every form of content unification, evidence shows that interdisciplinarity works both in enhancing student learning as well as in cognitive and affective domains. Mixing things up a bit can energize and refocus students. Looking at the world in new ways and permitting content to be viewed deeply and from multiple perspectives is one of the strongest reasons to recommend an interdisciplinary approach. Additionally, growing evidence shows that we must give students opportunities to see the world more holistically as we count on these students to solve increasingly complex problems. Moran (2002) is not alone in considering interdisciplinary thinking "the new critical idiom."

Teaching science outside the boxes

Science educators have long been advocates for instructional designs that blend the science disciplines. One such plan, coordinated science, uses the metaphor of cutting through the common "layer cake" approach, in which students have a full year of a specific science during their high school careers. The NSTA-initiated Scope, Se-

FIGURE 2

A proposed taxonomy of levels of intra- and interdisciplinary instruction in science.

Level 0 No cross discipline or interdisciplinary connections

Science is taught within the discrete, traditional subject area boundaries (e.g., biology, chemistry, Earth science, and physics).

Level I Intradisciplinary (low)

Science is taught using an approach that makes implicit connections between the sciences within the same classroom (e.g., general science).

Level II Intradisciplinary (high)

Science is taught using an approach that makes explicit connections between the sciences (e.g., coordinated or integrated plans).

Level III Interdisciplinary (low)

Science is taught by explicitly involving at least one other nonscience discipline within the existing science classroom (e.g., the unified, unit-based approach).

Level IV Interdisciplinary (medium)

Science is taught by explicitly involving at least one other nonscience discipline by coordinating with other instructors (e.g., exploring the physics of music with a shared unit developed by and involving both the science and music departments).

Level V Interdisciplinary (high)

Science is no longer the sole focus of instruction and many instructors and disciplines are engaged around the exploration of a theme or problem (e.g., students might study water from physical, chemical, and biological perspectives in science; examine the cost/benefit issues in social studies and economics; or consider the ways in which water is used as a metaphor in literature while reflecting on water through creative writing activities).

quence, and Coordination (SS&C) project (Aldridge 1992; Aldridge, Lawrenz, and Huffman 1997) recommended that students study each of the basic sciences each year through a carefully sequenced, well-coordinated plan of instruction involving separate teachers in separate classrooms. With teachers instructing in disciplines they already know, the likelihood of successful introduction of the SS&C plan was increased over other forms of cross-disciplinary teaching.

Many attempts have been made to blend the sciences further into what is often called "integrated science instruction." In the past few decades, this approach has gained a small measure of popularity, with some school districts developing entire science programs in which students take Science I, II, and III rather than the traditional biology, chemistry, and physics. Several texts, such as *Science Probe I and II* (Sokolis and Thee 1997) and *Integrated Coordinated Science* (Smith et al. 2004), have even been written to support such instruction. Both coordinated and integrated science are best characterized as intradisciplinary, because the blending of the disciplines does not involve domains beyond that of science itself.

The final plan for the most complete form of interdisciplinary science teaching has roots that extend back to the progressive era in education in the early 20th century. These plans, sometimes called "unified science," would easily be recognized by individuals like John Dewey who support project-based learning. Here the discipline walls are broken down with the requirement that students identify a problem of interest (e.g., the energy crisis) and let that guide them into any field that might inform their understanding of or solutions to the problem. Victor Showalter (1973) was a major advocate for the unified approach. He and his team at the Federation for Unified Science Education (FUSE) wrote and tested hundreds of units, each of which is based on a process, concept, persistent problem, or natural phenomenon. Unfortunately, little is known of FUSE today, but new versions of the project-based approach echo the FUSE philosophy (Colley 2008; Dickinson and Jackson 2008).

With these notions in mind, it may be useful to consider a classification scheme (Figure 2) based on the work of Klein (1996) and others but expanded and enhanced to focus on science instruction. This plan includes the distinction between intra- and interdisciplinarity and incorporates an "ease of implementation" factor. For instance, no matter how desirable, it is difficult to radically transform the curriculum by involving teachers outside of one's discipline, but interdisciplinary teaching does not always have to involve others directly. Every teacher in any discipline can design a unit or two that bridges the great divide between two or more ways of knowing and give students another way to look at the world. The classification plan provided here may be used as a road map to show both where you are and where you might go.

Interdisciplinary teaching: The challenges

The potential offered by any form of blended science instruction is high, but so too are the challenges. First, the education of science teachers provides one of the most significant roadblocks to the implementation of high levels of interdisciplinary teaching. Science teachers typically start out as biologists, geologists, chemists, and physicists, and, with few exceptions, rarely gain content knowledge too far outside their initial science realm. So, even intradisciplinary teaching can pose a problem that does not exist in other disciplines, such as in mathematics where teachers are more broadly educated.

Second, there is the issue of modeling. Few teachers have had an opportunity to experience true interdisciplinarity themselves as students. It is also not likely that a teacher is employed in a school setting where interdisciplinarity is practiced widely and, therefore, may have not had an opportunity to see such teaching in action.

Third, there is understandable resistance to change. Interdisciplinary teaching, even at a modest level, is a departure from the norm.

Finally, there are the pervasive external forces such as lack of planning time and the pressure to perform with respect to pacing guides and end-of-course examinations. If schools are interested in encouraging new ways to engage faculty and students, then time must be provided to plan the kinds of high-level instructional units that are the hallmark of a "curriculum without walls."

A discussion of these challenges is offered not to discourage the kind of innovation advocated here, but simply to acknowledge that good things are sometimes difficult to achieve. Conditions will likely never exist such that all classes can—or even should—be taught at the highest levels of discipline integration, but a quick examination of Figure 2 (p. 27) might provide reason to be optimistic. If educators might only respond to the call to move up one notch on the continuum (and then perhaps another), the radical transformation of science teaching can occur one step at a time.

Beyond Young

Even though Thomas Young was probably not the last person to know everything, he was most certainly a Renaissance thinker. His breadth of knowledge in widely disparate fields enabled him to make outstanding contributions that would have been most unlikely had he been a more traditional scholar with a narrow range of expertise. Perhaps we need a name for teachers who will encourage the next Thomas Young and who value interdisciplinarity, possess strategies for crossing discipline boundaries, and regularly provide opportunities to assist students in bridging the divides that separate domains of knowledge. Perhaps we should call these enlightened educators *Renaissance teachers.* ■

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