Completing the circuit: The feedback loop between metaphor and instruction

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Abstract

Metaphors have been used since ancient times to describe the learning process. Discipline-specific metaphors, in turn, have been used to enrich the learning process itself. This article discusses the concept of a "metaphor loop": a self-referential metaphor that ostensibly explains a specific topic to be taught, but which actually says something meaningful about education in general. These metaphor loops can be used to add a level of complexity and meaning to the teaching of almost any field of endeavor.

1. A simple metaphor.

"Imagine," I say to students on the first day of class, "that I am here to teach you how to play the piano."

There are usually some confused frowns here; after all, I teach physics, not music. "My teaching technique will be simple: I will sit at the front of the class, playing the piano, every day. You will listen attentively and take notes. You may even interrupt the music and ask questions, if you wish.

"At the end of the semester, you will be tested. Your test will consist of a recital in front of the entire class. Something by Chopin or Liszt or Prokofiev would be appropriate. I will assess how well you play, and your grade will be based upon that assessment."

Students are not shy in expressing how horrible this piano-teaching method sounds. Some students are visibly animated, ready to argue. Others are scowling with full-blown cognitive dissonance, wondering why the "physics" professor is rambling on about music. *Time to strike,* I say to myself, *while the iron is hot.* "What methods for learning the piano would be *better*?" I ask. "What do you suggest?" The class begins a lively discussion about teaching, learning, and the roles of professor and student. Eventually, a consensus is reached. "You can't learn a musical instrument without *practice*," the students invariably conclude.

"All right," I respond, pretending to concede a point, "practice will be an integral part of this class. What else?"

It is easy to imagine what happens next. With guidance the class works out a plan that includes practice, lecture, group activities, one-on-one feedback, listening, testing, and more practice. It is only then that I remind students that they are in this class to learn *physics*, not to play the piano. It dawns on students that this whole exercise has been a metaphor, intended to illuminate the learning process. *Practice* is a code word for *homework*, and the metaphorical lesson is that you cannot *learn* physics without *doing* physics yourself.

2. Metaphors of education.

There is a long tradition of using metaphors to describe learning and epistemology. In the *Republic*, Book VII, Plato describes a cave in which prisoners are chained, unable to see anything except shadows cast onto the wall (Shorey, 1935). To the prisoners, these shadows are “reality,” and no higher level ideas are understood or even imagined. But a prisoner who is freed will eventually see that these shadows are but a poor imitation of reality—such a prisoner has gained “wisdom”.

In the New Testament we find Jesus, in his role as a teacher, likening himself to light, a gate, a shepherd, and a vine upon which people grow (John 8:12, 10:9, 9:11, 15:5). Much later, we have Descartes-as-architect building a house, that is, his philosophy, upon a solid foundation (Cottingham, 1984).

One of the earliest educational metaphors is Plato’s student Aristotle advocating the “tabula rasa” model of learning: the idea that humans are a “blank slate,” upon which a teacher may “write” whatever information is desired (Ross, 1961). This model was of course later developed in great detail by John Locke in his *Essay Concerning Human Understanding* (Locke, 1690). More recently, we have Friedrich Fröbel’s concept of a child as a plant which needs to be nurtured if it is to bloom (Brosterman, 1997). This metaphor has been around long enough that we rarely consider the word *kindergarten*, coined by Fröbel, in its original translated German meaning: “children’s garden”. Nor, for that matter, do we think of the word *curriculum* in its original Latin sense as a “course to be run” (Lawton, 1984).

In the 20th century, R.S. Peters developed his “education as initiation” metaphor, which suggests that education is really an initiation into social traditions, specifically academia (Peters, 1965). We also have the idea of education as “liberation” from oppression, an idea which has roots in the early Marxist writings of Gramsci, most notably championed by Freire in his *Pedagogy of the Oppressed* (Freire, 1971; Lawner, 1979). In that same work Freire also derides the older tabula rasa metaphor by referring to students as “banks” into which knowledge is deposited. Other examples include the neo-Cartesian “curriculum as a framework” (DES, 1980), the tongue-in-cheek “teacher as caveman” (Benjamin, 1939), and the curriculum as a “jungle” (Aspin, 1984). And then there is the oft-repeated “education is not the filling of a pail, but the lighting of a fire,” which is apocryphally attributed to Yeats.

Other educational metaphors are brought up so frequently that they have become clichés. With overuse, once-fresh ideas seem stale: "…at first glance, the list of metaphors in education induces an oppressive sense of the banal" (Elliott, 1984). Other metaphors have had their meanings changed entirely. Politicians talk about the "accountability" of teachers and about "quality control" in the education system, without seeming to realize that they are evoking the metaphor of students as products of an assembly line (Taylor, 1981). Such imagery, when taken to its logical conclusion, can be as savage as students jumping into a meat grinder, as in Pink Floyd's hyper-metaphorical film *The Wall* (1982).

There is also a danger that metaphors, being so common, may be taken too literally, with some proposing to "dispense with metaphors altogether" (Entwistle 1970, p. 156; cf. also Komisar, 1961). The idea is that metaphors act as models—they provide a conceptual framework for understanding a given theory. But therein lies the problem: no metaphor corresponds to any model *exactly*; the correspondence is not one-to-one. Unfortunately, people often cling to their metaphors, instead of rightly abandoning them when correspondence breaks down. The metaphor-as-model construction, if it is to have any value at all, must "first be pruned of [its] more dangerous branches" (Taylor, 1984, p.10).

Metaphors serve other purposes as well. A good, catchy, metaphor acts as a tag that reminds us of a conceptual model, rather than serve as the model itself. Thus when one speaks of Quine's "web of belief" we are reminded not only of the book of the same name, but of the entire body of Quine's epistemology and theory of language (Quine, 1970). Of course metaphors can also serve a literary purpose as well: "I am a rock," said Paul Simon, "I am an island."

3. Metaphors in education.

We now move away from metaphors *of* education, to the use of metaphors *in* education. As a physics professor, I am most interested in metaphors as a way of stimulating students' thinking, encouraging them to make new connections. Metaphors, when used in this way, are similar to the thought experiments that Dennett calls "intuition pumps" (Dennett, 1984). For example, I often introduce electric current with a traffic metaphor. By imagining the flow of electrons to be analogous to cars on a highway, students will often propose Kirchoff's 1st Law on their own, with prompting. "The number of cars entering an intersection equals the number of cars leaving that intersection" becomes "the sum of all currents entering or leaving a junction in an electric circuit is zero," which in turn becomes

$$\sum_{i=1}^{N} I_i = 0. \quad (1)$$

To the student, the jump from metaphor to a description of Kirchoff's 1st Law requires an imaginative leap; the jump from this description of the Law to Kirchoff's 1st Law expressed in mathematic symbols is cognitively similar.

Note that I do not intend traffic to be a literal model for electric current. There are important differences—enough differences, in fact, that in order to propose Kirchoff's 2nd Law we already have need of a new metaphor entirely. My metaphor is probably more accurately called a simile ("electrons are *like* little cars on the highway") or an analogy ("the flow of current is *analogous* to the flow of traffic"). However, being a physicist, I retain the right to *not* discuss the semantics of *metaphor*, *simile*, *analogy*, or even *metonymy* (cf. Gentner, 1982).

I consider myself in good company when using metaphors to describe science. Newton was paraphrasing Bernard of Chartres when he said that he "stood on the shoulders of giants" when developing his natural philosophy. Darwin's "natural selection" is clearly an anthropomorphic metaphor. And when Einstein said that he was "convinced that He does not throw dice", he was subtly introducing two metaphors: that of the universe as a pantheistic God, and that of quantum mechanics as a game of chance (Einstein, 1926).

Spiraling outward, I will point out that the use of metaphor in instruction is limited only by the imagination of the instructor. An English professor may describe the works of Shakespeare as the wellspring from which all of Modern English flows. A history professor may describe World War I as the crucible in which 20th century sensibilities were smelted. A psychology professor may describe neurotransmitters approaching a neuron as barbarians storming the gates. As a physicist, I cannot vouch for the validity or usefulness of these off-the-cuff metaphors, but the point is clear: metaphor is a ubiquitous part of education, regardless of discipline. Such metaphors can enrich, enliven, and engage the student, and teachers should be encouraged to invent new ones specific to their individual fields of study.

4. Another metaphor: trick-or-treat.

I begin my lecture on the Doppler effect by drawing a house. I then draw a line of students equally spaced, approaching the house. The students are going trick-or-treating, I say, as the Doppler effect lecture typically occurs around Halloween. “What factors influence *how often* the kids arrive at your house?” I ask.

A bit of Socratic give-and-take yields two facts, which I write as

$$f \propto v, \tag{2}$$

and

$$f \propto \frac{1}{\lambda}. \tag{3}$$

The first expression, “frequency is proportional to velocity,” means that the frequency with which trick-or-treaters arrive at the house is proportional to how fast they are moving. The second expression, “frequency is inversely proportional to wavelength,” means that the frequency of arrival will *go down* if the spacing between the kids *goes up*. Students soon realize that the line of kids is a metaphor for a *wave*, such as a light wave or sound wave. The spacing distance is a metaphor for *wavelength*. When they have internalized these ideas, I push the metaphor further.

“Suppose now that this house, the one that the kids are approaching with such zombie-like regularity, is actually an RV. And suppose that you decide to drive the RV away from the kids, to try and avoid them. The kids are moving at 5 mph, and so if you drive faster than that, the kids will never reach the RV.

“However, suppose you are only able to drive away at 3 mph. The kids will clearly reach you *eventually*. What happens to the frequency?”

“The kids won’t reach the RV as often,” students say.

"Good. A physicist would say, 'the frequency has decreased as a result of the motion of the observer." My students have just been introduced to the Doppler effect. "Now let us imagine what would happen if you decided to drive *towards* the kids—not too fast! We don't want anyone hurt!"

And at this point, I say to myself, *not too fast with the lecture. I don't want the students to feel overwhelmed. I wouldn't want their knowledge to be "Doppler shifted."*

5. The metaphor/metaphor feedback loop.

We come now to the central premise of this essay, which is that discipline-specific metaphors used *in* education can often be co-opted to inform the discussion *about* education. In the language of electronics, there is a feedback-loop between the two levels of metaphors. I use a simple metaphor to explain the Doppler effect; in turn, the Doppler effect, as metaphor itself, speaks to my students about learning physics. I will call such a construction a "metaphor loop".

There is a double level of meaning inherent in the metaphor loop. This complexity adds richness to the students' learning experience. I talk about the Doppler effect; students begin to understand what the Doppler effect is, and how the concept applies to real life. I then let the Doppler effect itself become a metaphor: I allow the concept to loop back on itself, for the tiger to catch its own tail. "How does the Doppler effect apply to your own learning?" I ask. "What learning concepts correspond to frequency, and to wavelength?"

The discussion that follows is always fascinating: "Frequency corresponds to how quickly the professor talks."

"No, that would be velocity, not frequency."

"Wavelength is how much time occurs between homework assignments."

"That's just crazy! A time can't be a length."

"If we 'move away' from the professor, by resisting what he's trying to say, we won't learn as much. It's like the RV, not getting as many trick-or-treaters."

On one level, students are exploring ways in which they can learn physics—they are talking about the relationship between the professor, the student, and the knowledge and skills they are trying to acquire.

On another level, perhaps hidden to the students' consciousness, the students are internalizing and reinforcing the concept of the Doppler effect itself. By talking about physics, the students learn something about their own education. This in turn helps students master the physics concept that started the whole discussion in the first place!

I prefer metaphors specific to my own discipline because I value this double-layering; my original piano metaphor might be more effective in a music class. But regardless of discipline, metaphor loops are easy to find, once you start looking for them. Almost any concept can be re-worked in some way to say something about student learning. Students themselves can even be asked to come up with their own metaphors, perhaps as an in-class exercise or homework assignment. If a metaphor is a good one, then the student has found a new and creative way to speak about the entire education process. This can only help students in the long run. Even if the metaphor "fails" in some way, the student can still benefit. In discovering the ways in which the metaphor breaks down, the student still demonstrates creative thinking and self-reflection. And the student has thought carefully about a discipline-specific topic, learning something valuable in the process.

6. A random metaphor: quite the stretch.

As an example of how the process might work, I give here a discussion of a random physics topic that is probably unfamiliar to most non-scientists. I present the material as I would present it to a freshman physics class, and then attempt to "mine" a metaphor from the material to inform the broader discussion about physics education; whether or not the metaphor "succeeds" is not as important as the process itself.

"Suppose," I might tell my class, "that you have a wire, made of copper. You hang the wire from the ceiling and measure its length. Maybe it is 6 ft. long. You also measure its diameter, which is 0.25 inches. From this you can determine that the wire's cross-sectional area is about 0.049 square inches. You then hang a fifty pound weight from the end of the wire. The wire stretches by an amount we'll call S. The question is: what factors affect *how much* the wire stretches?

“Clearly, the more weight (*W)* that you put on the wire, the more it will stretch. We would say mathematically that $S \propto W$, or “stretch is proportional to weight.” It is also obvious that a ‘thicker’ wire would be stronger; indeed, it turns out that $S \propto 1/A$, “stretch is inversely proportional to area.” A bigger area means that the wire would stretch less. Strangely though, we find experimentally that *longer* wires stretch *more*, so we must also say $S \propto L$. Finally, the stretch depends upon what *kind* of wire we have; a piece of taffy would stretch much more than copper. Let’s call the wire’s ”resistance to stretching” *Y*, after the physicist who first popularized this approach, Thomas Young. We then have $S \propto 1/Y$. Putting all of these relationships together gives us the algebraic expression

$$S = \frac{LW}{YA}\,. \qquad (4)$$

In other words, the stretch of a wire depends upon four things. On the one hand, a longer wire will stretch more, and a larger weight will have the same effect. On the other hand, a larger cross-sectional area will cause there to be *less* stretch, as does increasing the wire’s ‘resistance to stretching’. If you’re keeping score, the mathematical expression says in 7 characters what the English says in 238.”

I would allow some time, perhaps a week, for students to learn this formula, the “elasticity” formula. They would perform in-class exercises and solve several homework problems. I might then re-introduce the elasticity formula, this time as metaphor.

“You come to this class with a set amount of knowledge about physics, which we will call *L* for ‘learning’. It is my goal as an instructor to help you increase that knowledge, to ‘stretch’ it if you will. By the end of the semester you might know a little more, be more ‘learned’. *L* will be increased by an amount *S*.

“The amount that you learn will depend upon many things. Those who have had physics before, or know a little calculus, may find that it is easier to learn even more. Knowledge helps beget more knowledge. So we could say that $S \propto L$. Of course the things that *I* say and do, as instructor, will obviously affect you learning experience as well. Maybe if I challenge you, push you harder, expect more out of you, then you will respond by being more receptive to the concepts we discuss. If we call the weight of my effectiveness W, then $S \propto W$.

"Now, some factors may hinder your experience. It could be that some people are stubborn, unwilling to learn, as bull-headed as a yak. Let's take Y to be yak-headedness, so that $S \propto 1/Y$. Similarly, you may not be intrinsically stubborn, but, for whatever reason, you present a façade of apathy, which we will call A. It's fair to say that $S \propto 1/A$, your learning is "inversely proportional to your apathy."

It is at this stage that students should be brought in, to discuss the metaphor, accept it, criticize it, modify it, and stretch it as far as it can go. They learn explicitly about learning, and implicitly about the original physics. Eventually the students may even ask questions that propel the physics further, into topics that have yet to be introduced. "What if the instructor pushes too hard, so that W is too large?" they may ask. "Well," I respond, "there may be a breaking point. If there is too much homework, students fail to learn at all. With the wire, if the weight is greater than a certain critical amount, the wire will break. This is called the 'elastic limit' of a material."

I won't belabor the metaphor any further. A seemingly "dry" topic like "elasticity" has been shown to provide a wealth of metaphorical language which the instructor can use to talk about the students' learning experience. In turn, the student has learned about stress, strain, Young's modulus, elastic materials, compression, pressure, and Hooke's Law. The feedback loop is complete: the tiger has caught its tail.

7. **A final metaphor: completing the circuit.**

In this essay I have introduced the idea of a lecture topic, such as the Doppler effect, itself becoming a metaphor for education, which in turn can help the understanding of the original topic. Thus, we can name this phenomenon a "metaphor loop", itself a metaphor meant to evoke the idea of a feedback mechanism. Let us develop this metaphor further, taking these ideas to their logical conclusion.

We begin with a demonstration that is well-known in the literature of physics education (Arons, 1973; Shaffer, 1992). University students are given a single wire, a battery, and a light bulb, and are asked to light the bulb. Many students, even science education majors, have difficulty with this task at first. As Arons observes,

> When these students are given a dry cell, a length of wire, and a flashlight bulb and are asked to get the bulb lighted, they almost invariably start by connecting the wire across the terminals of the battery and holding the bottom of the bulb to one battery terminal. They have no sense of the two-endedness of either the battery or the bulb… (Arons, 1973, p. 771).

The problem is that many students have strongly-held misconceptions about the way electricity works. A common misconception is that a battery is a “source” of electric current, and that therefore “electricity” should flow out of a battery and into a light bulb, thereby lighting it. This method fails (see Fig. 1) because there is no closed loop; in the language of physics, there is no complete circuit.

Why does there have to be a closed loop? The answer is that batteries do not *create* electrons, the particles that “flow” to make “electricity”; rather, batteries produce a situation in which electrons—already present in a wire—have “motivation” to move on their own. This “motivation” is called *potential*. In Fig. 1, there may or may not be a potential, but either way, a continual flow of electrons cannot be sustained. Instead there would be a bunch of electrons piling up on one end of the wire or the other. For a light bulb filament to light, there must be a *continual* flow of electrons; because there is no such flow, the light bulb remains dark.

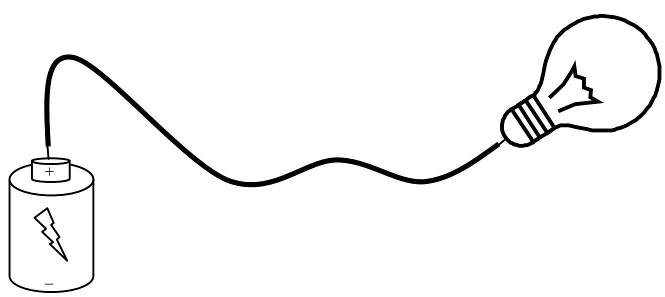

Figure 1. A failed attempt at lighting a bulb.

Fig. 2 is a successful configuration because it allows electrons to be *reused*. There is a continual flow of current from the positive terminal of the battery, into the bottom of the bulb, through the filament, out the side of the bulb, and into the negative terminal of the battery. The same electrons are used again and again. The bulb lights up.

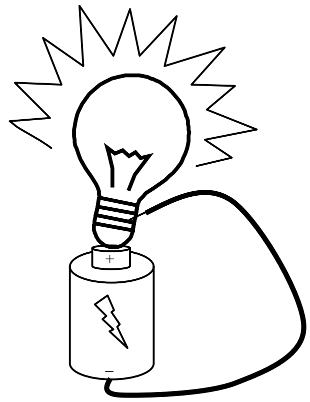

Figure 2. A successful lighting of the bulb.

Students have difficulty with this task because, as Arons pointed out, they do not realize that a bulb is “two-ended”. A battery is obviously two sided, having positive and negative terminals. But a bulb has two separate “entrances” as well: the nub on the bottom, and the metal threads on the side. Once students are aware of this fact, and understand that a complete circuit is required for electrons to be reused, the “light-the-bulb” task becomes much easier.

I find this task to be a powerful metaphor for the teaching process. The battery is the teacher: not operating solely as a source of knowledge, but hopefully instead as an agent that produces in the student the *potential* to learn more. A student that “gets” the material will have the metaphorical light bulb light up over their head; a student that does *not* learn remains in the dark.

Many students, and teachers, unfortunately, consider instruction a one-way street. Their expectation is that knowledge will flow directly from the teacher/battery into the student/bulb. But such an approach, like Fig. 1, is doomed to failure. A better approach is to have a complete circuit, from the teacher, to the student, and back again. Knowledge, like electrons, can flow both ways. Students are “two-ended” in that they can teach as well as learn. Teachers can learn as well as teach. Only by making a closed loop connection can students reach their full potential.

I have shared this metaphor loop with students, and the feedback (metaphor intended!) has always been positive. Students realize that they are active participants in an “education circuit” and that without their participation, learning will be minimal. Additionally, on a purely *physics* level, the concepts of potential, electric current, and electric circuits are enriched and reinforced. "Houston, we have a metaphor loop."

Interestingly, this circuit metaphor works on an even higher level—as a model for the entire "metaphor loop" concept itself. Thus we have a metaphor loop (the electric circuit) which itself is a metaphor for a metaphor loop. We should stop here before falling into an infinite regress, but I cannot help thinking of the *ouroboros,* the proverbial snake which swallows itself, a dream of which inspired August Kekulé to discover the chemical structure of benzene (Benfrey, 1958).

8. Conclusion

The physicist Douglas Hofstadter has proposed that consciousness itself is a meta-effect of feedback loops; when information loops back upon itself and reaches a critical level of complexity, consciousness emerges (Hofstadter, 2007). Whether or not one believes this thesis, self-referential behavior is certainly a fertile ground for metaphor and meaning. As Hofstadter points out, such behavior is ubiquitous in music (such as with fugues that loop back on themselves), art (such as the work of M. C. Escher), mathematics, and literature (in which an ending often echoes the beginning) (Hofstadter, 1979). It is natural to wonder whether such loops can infuse the structure of metaphors.

We have shown in this essay that this is, indeed, the case. The idea of a self-referential metaphor—what we call a "metaphor loop"—can be a powerful means for enlivening a student's experience. Such a loop can illuminate the education process, and in turn reinforce the discipline-specific topic that produced the loop in the first place. On an even higher plane, the feedback loop-as-metaphor says much about the process by which students and teachers interact. A professor is not simply a source of information, nor is the student simply a sink. Ideally, education is a self-referential process, and it is within this strange loop that the consciousness of learning resides.

References

Arons, A. (1973). Toward wider public understanding of science. *American Journal of Physics* **41**, 769-782.

Aspin, D. (1984). Metaphor and meaning in educational discourse. In Taylor, W. (ed.), *Metaphors of Education* (pp. 21-37). London: Heinemann Educational Books Ltd.

Benfrey, O. (1958). August Kekulé and the birth of the structural theory of organic chemistry in 1858. *Journal of Chemical Education* **35**, 21-23.

Benjamin, H. (a.k.a. Peddiwell, J.) (1939). *The Saber-tooth Curriculum, Including Other Lectures in the History of Paleolithic Education*. New York: McGraw-Hill.

Brosterman, N. (1997). *Inventing Kindergarten*. New York: Abrams.

Cottingham, J., et. al. (ed.) (1984). *The Philosophical Writings of Descartes* (Vol. 2, p.366). Cambridge: Cambridge University Press.

D.E.S. (Department of Education and Science) (1980). *Framework for the School Curriculum*. London: HMSO.

Dennett, D. (1984). *Elbow Room: the Varieties of Free Will Worth Wanting*. Cambridge: MIT press.

Einstein, A. (1926). Letter to Max Born (4 December). In Born, I. (trans.) *The Born-Einstein Letters* (1971). New York: Walker and Co.

Elliot, R. (1984). Metaphor, imagination and conceptions of education. In Taylor, W. (ed.), *Metaphors of Education* (pp. 38-53). London: Heinemann Educational Books Ltd.

Entwistle, H. (1970). *Child-centered Education*. London: Methuen.

Freire, P. (1971) *Pedagogy of the Oppressed.* London: Penguin.

Gentner, D. (1982). Are scientific analogies metaphors? In Miall, D. (ed.), *Metaphor: Problems and Perspectives* (pp. 106-132). Brighton: Harvester Press Ltd.

Hofstadter, D. (1979). *Gödel, Escher, Bach: An Eternal Golden Braid.* New York: Basic Books.

Hofstadter, D. (2007). *I Am a Strange Loop*. New York: Basic Books.

Komisar, B. (1961). “Need” and the “needs curriculum”. In Othanel Smith, B. and Ennis, R. (eds.), *Language and Concepts in Education*. Chicago: Rand McNally.

Lawner, L. (ed.) (1979). *Gramsci: Letters from Prison*. London: Quartet Books.

Lawton, D. (1984). Metaphor and the curriculum. In Taylor, W. (ed.), *Metaphors of Education* (pp. 79-90). London: Heinemann Educational Books Ltd.

Locke, J. (1690). *Essay Concerning Human Understanding* (Vol. I, p. 77). New York: Dover (1959).

Peters, R. S. (1965). Education as initiation. In Archambault, R. (ed.), *Philosophical Analysis and Education* (pp.87-111). London: Routledge and Kegan Paul.

Quine, W. and Ullian, J. (1970). *The Web of Belief*. New York: Random House.

Ross, D. (ed.) (1961) Aristotle’s *De Anima* (Book III, Ch. 4). Oxford: Oxford University Press.

Shaffer, P. and McDermott, L. (1992). Research as a guide for curriculum development: an example from introductory electricity. Part II: design of instructional strategies. *American Journal of Physics* **60**, 1003-1013.

Shorey, P. (trans.) (1935). Plato's *The Republic* (Book VII). London: Harvard University Press.

Taylor, W. (1984). Metaphors of educational discourse. In Taylor, W. (ed.), *Metaphors of Education* (pp. 4-20). London: Heinemann Educational Books Ltd.