Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025 ASEE
Paper ID #45458

Metaphors Matters: the implicit epistemology of how we talk about learning engineering

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Abstract

In this scholarly discussion, we argue that multiple metaphors for learning naturally arise while teaching engineering topics, and that being aware of them can aid student cognition. (We propose to use this topic for a discussion session, as noted in the CFP.) Many thoughtful faculty have moved away from transmissionist notions of teaching, in which the student is analogous to an empty vessel to be filled or a blank blackboard to be written upon. However, it is still possible to operate out of a dominant metaphor of learning as acquiring a thing, even if the mode of acquiring it is more active. Phrases such as instructors "delivering a lecture," courses "contain" or "cover" content, and students "grasping a concept" all point to thinking about learning as gaining an object. As Sfard [1] and others observe, we can also view learning as participating in a practice. This metaphor aligns with engineering mindsets, wherein we often care less about what students know, and more about what they can do with their knowledge. This shift in metaphor suggests that multiple approaches to learning may be needed for different subjects. How do other common metaphors, such as learning as lighting a fire and planting a garden, influence how we teach? Drawing on Ingold's anthropology of lines [2], we outline how metaphors such as learning as path-finding and learning as path-making align more precisely with engineering professional practice, as described in Vincenti [3] and Vermaas [4]. Reviewing the myriad options for characterizing learning, we describe how these metaphors create an instinctive understanding of engineering epistemology, and discuss the implications for engineering teaching practice.

Introduction: The Unavoidability of Metaphor

Drawing on Lakoff and Johnson [5], metaphors, for the purposes of this discussion, are when people make an association between two domains, drawing parallels between multiple features (see Figure 1). The more features that can be viewed as parallel, the stronger the metaphor. No metaphor is perfect; that is, we cannot draw parallels of all features between the two domains. Colloquially, we say that our metaphor "breaks down" at certain points.

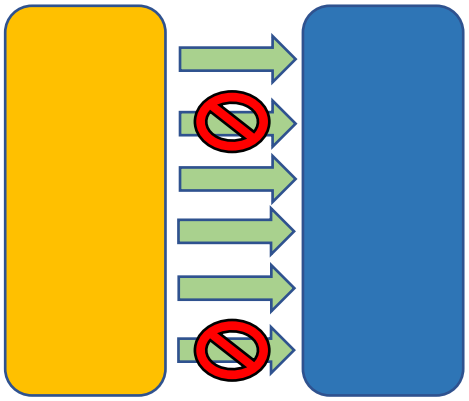

Figure 1. A metaphor draws parallels between two domains, although not all features map exactly.

People use metaphors in their thinking at a pre-linguistic level [5, p. 272], and metaphors can be embedded in concepts so basic that they are nearly invisible. One such metaphor is the notion that UP IS MORE [5, p. 15]. Extensions of this are UP IS GOOD, DOWN IS LESS, and DOWN IS BAD. (*Note: this discussion follows the notation of Lakoff &*

Johnson, which uses all caps to denote metaphors, to set them off as concepts and make reading easier.) This appears in all manner of our communications, including everyday phrases such as "things are looking up" and "I'm feeling down."

In fact, this fundamental metaphor pervades much of Western Culture, and appears in such diverse fields as religion (HEAVEN IS UP, HELL IS DOWN) and Cartesian graphs used in expressing algebraic functions (UP AND RIGHT IS MORE, DOWN AND LEFT IS LESS). Noticing the underlying metaphors embedded in how we think about complex subjects can:

1. reveal what is otherwise obscured by those metaphors and
2. initiate the search for new metaphors that might open creative and generative paths of understanding.

In this exploration of metaphor, learning, and specifically learning engineering, we suggest that this process of noticing current and creating new metaphors can be a means of reinvigorating our work as engineering educators.

What Metaphors Do

Metaphors perform work for us, intellectually, and metaphors we share communally are especially useful. For instance, thinking and ideas are rather nebulous. Shifting to IDEAS ARE OBJECTS allows us to "handle" ideas, e.g. *do you grasp this idea?* Taken further, we can view groups of ideas, such as theories, as solid objects, e.g. *our work is built on the foundation of this theory.*

Metaphors do even more work for us when they are novel and create surprising or new connections for us. This is the sense we traditionally discuss in literature, since the poetic use of metaphor is typically how we are introduced to the idea. In this sense metaphors both hide and reveal the assumptions we make about the domains involved in the metaphor.

Learning as Acquisition

In line with IDEAS ARE OBJECTS, it follows that learning is viewed as obtaining these objects: LEARNING IS GAINING A THING. This is clear in many of the ways we speak about learning and teaching:

- delivering a lecture
- covering the content
- grasping a concept
- giving students tools for their toolbox
- students complaining that they 'just aren't getting it'

Anna Sfard, a psychologist specializing in mathematics education, points out that this is the dominant metaphor of learning, as well as the shortcomings of focusing only on this one metaphor [1]. Paulo Freire uses a banking metaphor, that teachers seek to make deposits of knowledge into students' minds, to critique educational systems that are ineffective and even

oppressive [6], and many other educators also work to avoid "transmissionist" ways of thinking about teaching and learning.

Even if instructors have moved away from the "blank slate" or "empty vessel" metaphors for their students, in which students are passive, LEARNING IS GAINING A THING still dominates our conversation in research that examines "learning transfer" or "knowledge acquisition," even as courses are restructured for "active learning." For example, physics education researcher Edward Redish uses an extended metaphor he calls the "dead leaves model," in which students pick up information like dead leaves off the ground, with no comprehension of how they fit together or even that they were all attached to the same branch. He asks, how might we, instead, communicate about a discipline so that students perceive how all the leaves are connected on one "living tree"[7]? This is a useful metaphor, but notice that it still treats learning as an act of acquisition.

Focusing on learning as an acquisition creates parallels of features between the two domains (handling objects and learning) that do not exist in reality. For instance, once gained, a physical object will reliably be in a person's possession. However, without repeat usage, things we learn fade from memory. The "forgetting curve" was first experimentally derived in 1885 [8] and has been robustly verified (see Figure 2).

Many of us know this from our personal experience as well. How many of us have forgotten equations, concepts, or people's names that we used to recall easily, once we stopped using them regularly? As early 20th century education reformer John Dewey notes:

> [the educator] must constantly regard what is already won [learned] not as a fixed possession but as an agency and instrumentality for opening new fields which make new demands upon existing powers of observation and of intelligent use of memory. Connectedness in growth must be his constant watchword.[9, p. 75]

If "connectedness in growth" should guide how we teach, what metaphors would better serve us?

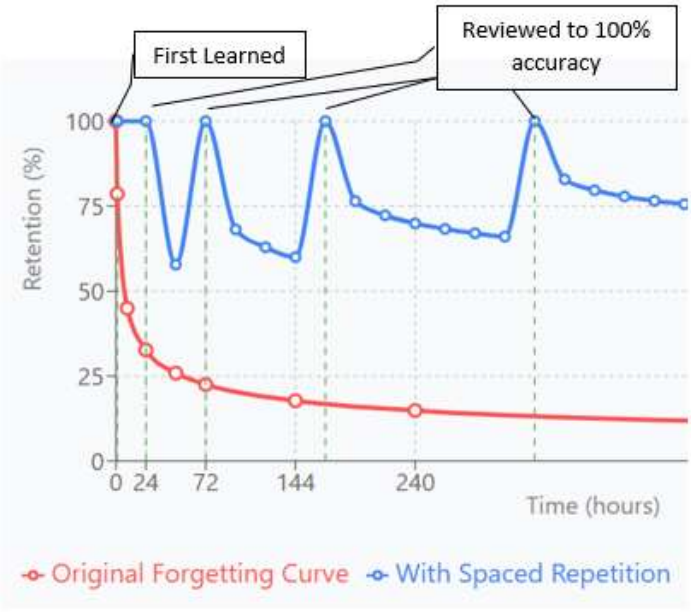

Figure 2. The Forgetting Curve, first described by Ebbinghaus (1885).

Learning as Participation

Sfard suggests a second powerful metaphor for learning is learning as participation, which we might call LEARNING IS PARTICIPATING [1], [10]. Aligned with ideas of apprenticeship, practice, and agency, LEARNING IS PARTICIPATING emphasizes ideas of movement, growth, and of participating in a community, as described by Lave and Wenger [11]. It also aligns well with the needs of engineering education, which often value not only "what you know" but also "what you can do with it."

LEARNING AS PARTICIPATING also emphasizes the nature of learning engineering (among other things) that requires practicing a skill, sometimes many times, before the conceptual understanding "clicks" for a learner.

Just as LEARNING IS GAINING A THING can take on specific variants, so too can LEARNING IS PARTICIPATING. For instance, it can be useful to consider the work of Tim Ingold, who explores the idea of the line, both literally and metaphorically [2]. Ingold describes people learning to follow paths, as gaining "wayfarer knowledge" – a person who experiences knowing a place as following a path through it [2, p. 92]. If we see wayfaring as a specific instance of LEARNING IS PARTICIPATING, then wayfaring involves teaching students to read maps, follow directions, notice landmarks, and adapt to shifts in weather. We might draw parallels to working through a process, noticing if calculations match rough estimates, or debugging software, all in an effort to "stay the course" and replicate journeys others have completed. Whereas LEARNING IS GAINING A THING implies students learn once I hand them the map, LEARNING IS PARTICIPATING implies that they have not learned until they have taken the journey themselves.

Ingold also describes "inhabitant knowledge," wherein knowledge "builds up, from an array of points and the materials collected therefrom, into an integrated assembly." An expert engineer, troubleshooting a system, might be able to move from any point on the "map" to another, without a path, because they know the place "forward and backward." In essence, they can make new paths. Here we extend this metaphor a bit further, as it relates to learning engineering.

We turn to the work of Vermaas et al. [4], who in turn were building on Vincenti [3]. In their discussion of engineering work, they note that engineers are most often engaged in "normal design," or reconfiguring known processes and artifacts. This work can be viewed as similar to the wayfarers who have learned to follow paths. In contrast, "radical designs" are those that must create new engineering artifacts and processes to accomplish the goal – generating "technological innovations." Presumably these new innovations can be re-used by others in normal designing in the future. In order to accomplish these "radical designs," they must reach the point of "inhabitant knowledge" – that is, they must go from path-followers to path-builders.

In learning engineering, students are not often creating new engineering knowledge. They are learning how to read the path and follow a map. Perhaps we could extend the metaphor and say they are also learning when they have strayed from the path and must re-locate it. As they continue learning, they gain inhabitant knowledge, the ability to make paths to leave for others to follow.

Path Following and Path Making

As specific variants of LEARNING IS PARTICIPATING, we find path-following and path-making as particularly salient for students. Engineering is a creative activity, and if we only portray engineering work as path-following, we misrepresent the work and likely deter the students who have the greatest sparks of ingenuity.

Recall that metaphors are supposed to "do work" for us. Discussing this process with students opens their understanding of their learning process. It steers them away from a mindset of "study for the test today, forget it tomorrow" and encourages them to value practicing their skills and seeking to see connection among the topics they are learning.

Sidebar About Other Metaphors

Additional metaphors related to learning include "lighting a fire" or "planting a garden," among others. These might be viewed as specific instances of LEARNING AS PARTICIPATING. Note that these metaphors relate more directly to the act of teaching, and de-center the students, turning them in to a candle or a plot of land.

Balancing the Metaphors

No one metaphor may be able to do everything we need for describing learning, a complex concept and task. We should maintain cognitive flexibility, not unlike being able to understand light as both wave and particle, and be willing to shift our view of learning. Perhaps more critically, we must be able to express our shift, from LEARNING IS GAINING A THING to LEARNING IS PARTICIPATING and back again, to our students, so that they perceive the importance of both aspects of their work as learners.

When should we move from one to the other? Here the concept of co-contraries is useful. As Goldberg and Somerville describe, co-contraries are pairs of concepts that are opposites, but also need each other to function [12, pp. 43–45]. The most basic example is *inhale && exhale*. Both are healthy actions, and when one is taken too far, we need the other. Other examples include *stability && change, theory && practice,* and *collaboration && individual work.* We propose viewing learning as *gaining a thing && participating* as a new co-contrary.

How can we tell if one of our learning metaphors has been taken "too far?" There are often signs that leaning into that metaphor is hampering our students' ability to become successful engineers (see Figure 3). Viewing learning as acquisition becomes problematic when students treat it as a series of things to be memorized, with no bearing on the activity of engineering. Learning as participating becomes problematic when lack of specific factual knowledge hampers engineering processes. And there are likely other signs that our use of one metaphor or the other has gone too far.

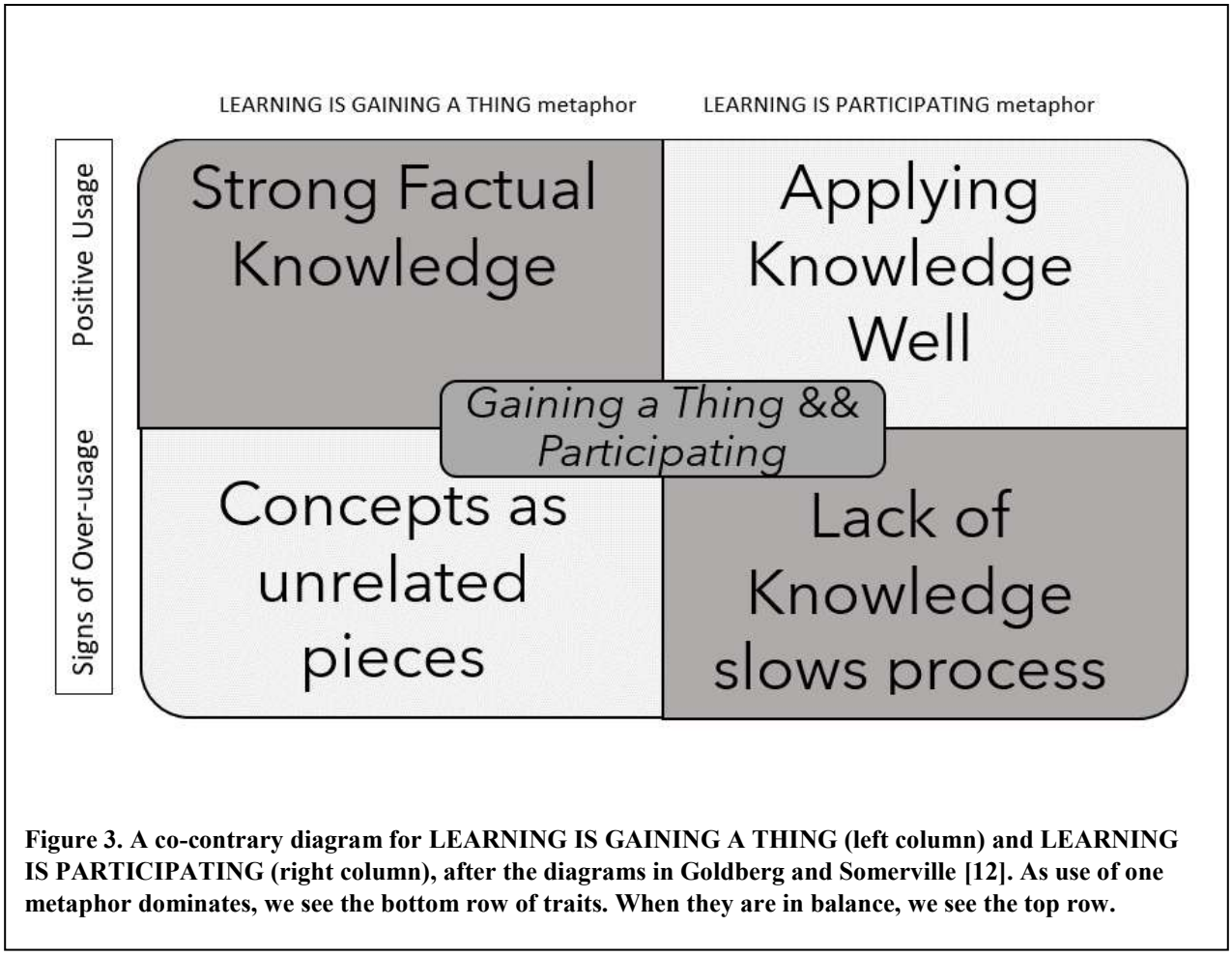

Figure 3. A co-contrary diagram for LEARNING IS GAINING A THING (left column) and LEARNING IS PARTICIPATING (right column), after the diagrams in Goldberg and Somerville [12]. As use of one metaphor dominates, we see the bottom row of traits. When they are in balance, we see the top row.

Looking Forward

The acts of learning and teaching are shifting now, with the broader introduction of generative artificial intelligence tools (genAI). Engineering educators may find they need the conceptual shift from LEARNING IS GAINING A THING to LEARNING IS PARTICIPATING to cope with these changes. As Bowen and Watson have suggested, one method is to assess students' process rather than a final product to measure what they have learned [13]. As genAI continues to develop and gets integrated into engineering work, it becomes even more critical that engineers have the expertise to judge genAI outputs, iterate with those tools, and go beyond predictable answers. They need to continue to bring empathy, ingenuity, and creativity to the various fields of engineering.

This is only the most recent reason for developing greater cognitive flexibility around our metaphors and striving to become more adept at guiding our students to view their learning as active, flexible, and continually growing.

Acknowledgements

The author wishes to thank the reviewers and audience of the 2023 Forum on Philosophy, Engineering, and Technology (fPET) who gave extensive feedback on early formulations of these ideas.

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