Cognitive Scientists Prefer Theories and Testable Principles With Teeth

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Alexander, Schallert, and Reynolds (2009/this issue) proposed a definition and landscape of learning that included 9 principles and 4 dimensions (what, who, where, when). This commentary reflects on the utility of this definition and 4-dimensional landscape from the standpoint of educational psychologists who have a cognitive science perspective. Their analysis has practical value in positioning different research programs in the landscape, planning research road maps, and identifying the scope of research efforts. However, it is argued that the learning definition is underspecified and that the learning landscape is both cumbersome and insufficiently constrained. Cognitive scientists are more likely to be inspired by theories and testable principles that have more teeth.

The article by Alexander, Schallert, and Reynolds (2009/this issue) has the ambition of offering a useful definition of learning. They begin by identifying nine principles of learning (such as learning is change, learning can be resisted, learning is interactional) that are shared by different research communities. They also specify what learning is not. Learning is not merely an innate capacity, a maturation of a biological/neurological mechanism, or the recall of prior material. Alexander et al. subsequently characterize human learning “in a topographical framework, a quadrangulation based on the convergence of the what, where, who, and when dimensions of learning” (p. 189). I refer to this topological quadrangulation as a learning landscape in this article. Alexander et al. apply this learning landscape to three cases that include a child biting into a cherry with a pit, an adult crossing a busy street in Italy, and a student writing a paper in a new discipline.

There are many motives for a group of researchers to define learning. It promotes coherence in the discipline to the extent that enough researchers are on board and some semblance of convergence is achieved. The learning landscape provides a perspective to position different theories. Researchers who are engaged in theoretical disputes often are merely positioned at different regions of the landscape, so the debates degenerate into pointless turf battles (in this case, “My turf is more important than your turf”). When projects are positioned in the broad learning landscape, empty regions become apparent and help guide the development of research road maps. The learning landscape undoubtedly broadens everyone’s perspective, emphasizes interactions between dimensions, and strengthens common ground among different research communities.

The goal of this commentary is to analyze the Alexander et al. (2009/this issue) definition of learning and the learning landscape from the standpoint of educational psychologists who are influenced by contemporary cognitive science. Cognition in the cognitive science arena is not limited to “cold” cognition but strongly embraces motivation, emotion, and social interaction. It is important to point out that cognitive scientists are interdisciplinary in the sense that they adopt theories and methodologies from multiple disciplines: psychology, computer science, linguistics, anthropology, discourse processing, education, neuroscience, the list goes on. From the standpoint of education, cognitive science has a strong presence in professional groups that are explicitly interdisciplinary, with labels such as Learning Science, Cognition and Instruction, Artificial Intelligence in Education, Intelligent Tutoring Systems, and Computer-Supported Collaborative Learning. Thus, the research community of relevance here is not limited to the prototypical cognitive psychologist who works in a narrow laboratory paradigm on cold cognition. With this context in mind, what would an educational psychologist with cognitive science leanings have to
say about the Alexander et al. definition and landscape of learning?

**HOW USEFUL IS THE ALEXANDER ET AL. DEFINITION OF LEARNING?**

A first step is to inquire whether the nine principles are technically adequate for a definition of learning. The definition of learning that Alexander et al. (2009/this issue) propose has the following nine principles (p. 178):

1. Learning is change
2. Learning is inevitable, essential, and ubiquitous
3. Learning can be resisted
4. Learning may be disadvantageous
5. Learning can be tacit and incidental as well as conscious and intentional
6. Learning is framed by our humanness
7. Learning refers to both a process and a product
8. Learning is different at different points in time
9. Learning is interactional

The purported advantaged of this definition is that diverse groups of educational researchers allegedly accept these principles as true.

One concern about this definition is that it does not have teeth and may not go the distance in identifying what is versus what is not learning. A classical definition of any concept C has a set of features that are necessary and jointly sufficient to discriminate C from non-C entities. A probabilistic definition of a concept has a set of features that are more frequently associated with C than non-C entities. There are also fuzzy definitions, prototypical definitions, and exemplar definitions of concepts (Smith & Medin, 1981), all of which attempt to discriminate C from non-C entities. The problem with the Alexander et al. (2009/this issue) definition is that is pitched at such an abstract level that it will not invite inquiry, controversy, concrete programs of research, and applications. It is interesting to compare their nine principles with the seven cognitive principles of learning that were identified in a practice guide for teachers on Organizing Instruction and Study to Improve Student Learning (Pashler et al., 2007), an initiative of the Institute of Education Sciences (IES) of the U.S. Department of Education. A consensus emerged for the following seven principles among researchers in the cognitive community.

1. Space learning over time.
2. Interleave worked example solutions with problem-solving exercises.
3. Combine graphics with verbal descriptions.
5. Use quizzing to promote learning.
6. Help students allocate study time effectively.
7. Ask deep explanatory questions.

These principles were both theoretically motivated and supported by empirical evidence that varied from low to high. There were also concrete examples in the practice guide on how teachers would apply these principles in the classroom.

Evidence-based principles of learning have been proposed by other research communities in cognitive science. For example, 25 cognitive principles of learning were proposed by a community of researchers affiliated with Lifelong Learning at Work and at Home (Graesser, Halpern, & Hakel, 2008), an initiative launched by the Association of Psychological Sciences and an earlier joint initiative between Association of Psychological Sciences and the American Psychological Association. The 25 principles included the aforementioned seven proposed by IES plus an additional 18, such as (with the original number identifications)

(3) Dual Code and Multimedia Effects. Materials presented in verbal, visual, and multimedia form richer representations than a single medium.
(7) **Generation Effect.** Learning is enhanced when learners produce answers compared to having them recognize answers.

(8) **Organization Effects.** Outlining, integrating, and synthesizing information produces better learning than rereading materials or other more passive strategies.

(9) **Coherence Effect.** Materials and multimedia should explicitly link related ideas and minimize distracting irrelevant material.

(10) **Stories and Example Cases.** Stories and example cases tend to be remembered better than didactic facts and abstract principles.

(11) **Desirable Difficulties.** Challenges make learning and retrieval effortful and thereby have positive effects on long-term retention.

(12) **Cognitive Disequilibrium.** Deep reasoning and learning is stimulated by problems that create cognitive disequilibrium, such as obstacles to goals, contradictions, conflict, and anomalies.

(13) **Cognitive Flexibility.** Cognitive flexibility improves with multiple viewpoints that link facts, skills, procedures, and deep conceptual principles.

(14) **Goldilocks Principle.** Assignments should not be too hard or too easy, but at the right level of difficulty for the student's level of skill or prior knowledge.

These principles of learning once again emphasize the cognitive foundations of learning, as well as metacognitive mechanisms (Hacker, Dunlosky, & Graesser, 2009). Additional principles would be needed to cover other regions of the learning landscape, such as motivation, emotion, discourse, social interaction, personality, development, and neuroscience.

All of the cognitive principles have testable predictions, which make their epistemological status very different than the definitional principles of Alexander et al. (2009/this issue). It is argued here that these testable principles proposed in the IES practice guide and lifelong learning initiative are more useful than the nine definitional principles of Alexander et al. The testable principles are more seductive in inviting inquiry, research, debate, and inspiration. These are claims with teeth that prompt curious souls to conduct research that have clear-cut testable predictions, to identify conditions where the principles break down, to debate those who challenge the claims, and to apply the wisdom to educational settings. In contrast, the definitional principles are truisms that are widely accepted, but hardly a stimulus for inquiry.

**HOW USEFUL IS THE LEARNING LANDSCAPE?**

The Alexander et al. (2009/this issue) learning landscape is a "topological quadrangulation" with the dimensions of what, who, where, and when. Building a landscape with multiple dimensions is an important early step in getting a handle on any phenomenon, so it is wise to do so for learning. As Alexander et al. aptly point out, the various researchers, theories, and educational programs can be positioned in specific regions of the learning landscape.

The notion of a multidimensional landscape to guide psychological research and practice has a very long history. More than 3 decades ago, Jenkins (1979) presented a tetrahedral model of learning and memory which posited four interacting factors that determined learning outcomes: criterion measures (desired learning outcomes), characteristics of the learners (skills and prior knowledge of students), nature of the materials (curriculum, texts, etc.), and learning activities (student behaviors and learning strategies). The RAND Reading Study Panel (Snow, 2002) identified four dimensions of reading comprehension: the reader, the text, the task, and the sociocultural context. In my own research on question asking and answering (Graesser, Ozuru, & Sullins, 2009), the four dimensions were the questioner's goals, the question category, the type of knowledge, and the type of cognitive process. Sometimes there are only three dimensions in these conceptual landscapes, as in the case of Sternberg's models that range from the triarchic theory of intelligence (Sternberg, 1985) to the triangular theory of love (Sternberg, 1986). I am unaware of any five-dimensional landscapes, perhaps because it is hard enough to get humans to imagine four dimensions.

Researchers will undoubtedly disagree on which dimensions to include in any multidimensional landscape. The Alexander et al. (2009/this issue) landscape emphasizes a developmental dimension (when) whereas that was absent in Jenkins' tetrahedral model. The landscape loads a lot of information into the what dimension, whereas the other four-dimensional landscapes just mentioned split off separate dimensions for knowledge, cognitive processes, materials, and/or criterion measures. The relevant dimensions clearly differ among research communities. The Alexander et al. article has attempted to incorporate the views of the different educational communities and ended up converging on the what-who-where-when solution. Time will tell whether this four-dimensional space ends up being adopted.

It is important to emphasize that the learning landscape is an atheoretical space, not a theory. One argument put forth in this commentary is to push the educational psychology further. The educational enterprise needs to move from merely recognizing the landscape to specifying what their theories predict within the landscape. The theories need to offer claims with teeth, testable principles, potentially counterintuitive mechanisms, and a decisive foundation for practice. Otherwise the learning landscape will be a barren, uninspiring desert.

As an appreciator of landscapes, I am somewhat discouraged that the Jenkins tetrahedral model ended up having such a modest impact on cognitive research in learning and memory. The tetrahedral model has undeniably had an
impact on some researchers from the standpoint of widening the landscape beyond narrow laboratory paradigms and educational practices. However, it is not that model that drives research. Instead, research is driven by more focused theories and testable principles. So this raises a question. Why hasn’t the landscape metaphor driven our research agendas over the last 30 years? There are at least four reasons, as elaborated next.

First, a four-dimensional landscape is difficult to imagine. Researchers are not prone to follow a metaphor that is difficult to visualize and that strains cognitive capacity. A single dimension is easy to handle and explains why simple main effects and constructs like \( g \) are so pervasive in the field. Two dimensions are also quite manageable, as in the case of two-way interactions and tradeoffs between variables. Three dimensions push the boundary for most researchers, but imagining a three-way interaction can be achieved with enough thought, time, and effort. Constructing four dimensions is a struggle for everyone and four dimensions is impossible to depict in both text and hypermedia. Cognitive researchers turn to a different metaphor when a model is extremely complex, as in the case of production systems, connectionist networks, dynamical systems, and other models that require computer simulations.

Second, empirical tests of a four-dimensional landscape create a combinatorial explosion problem. Consider the simplest case where there is only one variable per dimension and two values per variable. The number of cells in the factorial arrangement would be \( 2^4 = 16 \). So if there were 20 observations per cell, the minimum total size would be 320. However, quite clearly, a researcher would want to consider three values per variable, as in tests of curvilinear relationships and contrasts between a treatment and multiple conditions. In this case, the number of cells in the factorial arrangement would be \( 3^4 = 81 \) and the number of observations would be 1,620. A thorough researcher might consider two variables per dimension which would yield \( 3^2 = 6561 \) cells and 131,220 observations. There are not enough people on the planet to run a between-subjects design with 4 variables on 4 dimensions. Tests of a four-dimensional landscape are impractical, if not impossible.

Third, four-dimensional interactions are challenging to explain and replicate. Researchers who have tried to pin down these complex interactions are faced with the difficult task of communicating them to fellow researchers. The interactions do not replicate unless the values of the variable are precisely tuned. At that point the only defensible conclusion is that there are sometimes high-way interactions among the four dimensions. This is not new news of, of course, because it has been known for centuries that there are interactions among levels in any system.

Fourth, theories with constraints are more inspiring than four-dimensional landscapes. Researchers get most excited when they test their pet theories that generate testable principles with predictions. The theories can vary in whatever complexity the particular researcher can handle and that does justice to the phenomenon under investigation. Some theories are narrow and others very broad. The scope of a theory need not cover a large terrain in the four-dimensional landscape. Simplicity and elegance frequently trump breadth and complexity.

THE VALUE OF THE ALEXANDER ET AL. DEFINITION OF LEARNING AND THE LEARNING LANDSCAPE

The central argument in this commentary is that educational researchers are most inspired by theories and testable principles. Moreover, the most captivating seductive theories and principles are those that have teeth. That is, the predictions are decisive, readily falsifiable, sometimes counterintuitive, and/or incompatible with the prevailing wisdom of relevant communities. Theories and testable principles drive research programs, not definitions and landscapes.

Nevertheless, it is important to reiterate how the Alexander et al. (2009/this issue) analysis is valuable to educational psychologists. The learning definition and landscape is helpful for “herding the cats” under some semblance of a common vision. It is needed to communicate what the field is all about to students, faculty, politicians, citizens, and educational practitioners. It is needed when composing a research roadmap for funding agencies that want to plan a research agenda for the next 5 or 10 years. The landscape uncovers salient gaps in the terrain that might stimulate new research initiatives. We can identify when there is a fundamental clash between two research paradigms (e.g., two theories covering the same turf, but with opposing predictions) versus the more frequent case where two research paradigms are merely investigating different regions of the landscape. The learning landscape offers a broad perspective for assessing the scope and generality of a theory or testable principle. These are the ways that Alexander et al.’s contribution has tremendous value.

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