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Useful Metaphors for Tackling Problems in Teaching and Learning

Textbooks and lectures are typically structured around the belief that students learn the same way they would climb a ladder: straight up, one step at a time. Marc Schwartz and Kurt Fischer propose a pyramid and webs of pyramids as far more appropriate and useful metaphors.

by Marc S. Schwartz and Kurt W. Fischer

STUDENTS LEARN important concepts and ways of thinking by building on their own actions and experiences. In much of higher education, the primacy of textbooks and the lectures that accompany them are inconsistent with the nature of student learning. Some students manage to learn despite the problems from this emphasis, but we educators can do much better. Good teachers can shift the chemistry of their classes to build on the dynamics of the learning process and use texts and lectures from their discipline as supports for learning instead of having textbooks and lectures dominate the curriculum. This article offers an approach from cognitive science intended to help educators facilitate active student learning using these traditional disciplinary materials.

So Much to Cover

AS THE AMOUNT OF KNOWLEDGE in academic disciplines has expanded, the textbook has become heavier, the number of volumes has ballooned, and the amount of information to be covered in the lecture has increased. One problem from students' point of view is that the textbook sets up an unrealistic standard for what is expected of them but no plan for how to learn what is within the covers. Must students memorize all those important facts? Is the goal of class lectures to signal which are the really important facts from these books? How can students get beyond lists of facts to get hold of the important concepts and arguments that frame those facts? As more and more facts accumulate in the current knowledge explosion, the educator's responsibility is to teach concepts and frameworks for dealing with these facts rather than merely present them.

Textbooks, and lectures designed to wrap around them, also pose a problem of pedagogy. Teachers often place too much faith on what the textbook can deliver and downplay the importance of their own interaction with students. Contrary to this approach, which we have seen most frequently in science, mathematics, and engineering, college educators and their students benefit from teaching and learning that moves beyond the textbook and lecture. We believe that centralizing textbooks and lectures have, for too long, constrained the imagination and potential of teachers and students.

The Nature of the Problem

IN MANY COLLEGE COURSES, instructors—who often rely heavily on their disciplinary textbooks—feel a responsibility for presenting the legacy of their field to their students. Howard Gardner, in *The Disciplined Mind,* suggests that the disciplines make important contributions to societal knowledge and organize how knowledge is built as well as how jobs are created and defined. The goal of teaching, then, is to help students master the main knowledge defined by the discipline. Two often neglected questions are how students can effectively build an understanding of that knowledge, going beyond a recitation of facts, and how instructors can assess their understanding.

The legacy of the discipline, preserved in writing and in the collective memory of teachers, is typically revealed to students through reading, lecture, and demonstration. Successful students manage to relate their classroom experience to their lives and recognize how the curriculum influences their understanding of the world. In the sciences, we, along with Jerome Bruner, David Perkins, and others, have extensively criticized the reading-and-lecture model of learning. In science disciplines, instruction has received extensive criticism for failing to teach students how science proceeds and how scientists develop knowledge and for failing to teach effectively the knowledge generated through scientific inquiry.

The textbook plays a key role in shaping current modes of teaching and learning. It typically frames the problems of the discipline, offers the solutions, and defines the facts to be presented in the lectures. Even teachers who do not assign textbooks for students to read will often organize their lectures based on a textbook framework. The text is typically organized by the history of the discipline, the problems it has faced, the solutions found, the problems that still remain, and the tools and models the discipline uses to make sense of the phenomena it studies. A good traditional textbook will address these areas in a logical, readable, thorough, concise, well-illustrated, and well-referenced style.

From the student's point of view, the textbook and lecture present a world full of new vocabulary, people, ideas, phenomena, and models yet to be coordinated and understood. What do the textbook and teacher mean by Newtonian forces, universal justice, or postmodernism? Initially, text and lectures do not appear to be a solution to any problem a student understands, because he or she has not yet personally connected with the problems defined by the discipline. For the student, the textbook itself is a problem to overcome. What is important? Why is it important? How can he or she come to understand the concepts (and, of course, do well on the tests or essays)?

From the student's perspective, the challenge posed by lectures and textbooks is to understand the representations and abstractions offered. But what does that understanding look like, and the important question for instructors, what counts as satisfactory understanding? The skill theory of development that we present here suggests a strategy for analyzing the challenges faced by both instructors and students and offers possible methods for overcoming hurdles posed by textbook-based pedagogy. Our ultimate goal is to help students profit from the stored treasures within disciplinary texts and lectures.

A Method for Measuring Understanding

A SCALE FOR COGNITIVE COMPLEXITY suggested by cognitive and brain development research offers a powerful approach for analyzing skills in any domain. This scale, described by Kurt Fischer and Thomas Bidell in *Handbook of Child Psychology,* derives from studies into the levels of understanding that people naturally develop as they build their skills from infancy through childhood and into adolescence and adulthood. This thirteen-level scale can be used to evaluate students' understanding as they seek to integrate disciplinary concepts and facts with their own experiences and activities.

During the first thirty years of life, people develop

Students rarely move in a predictable trajectory toward understanding. The underlying structure of the learning process is developmental and cyclical in nature.

through four distinct *tiers* of understanding comprising these thirteen developmental levels. The final ten of these levels are most relevant for education. Each tier serves as a foundation for the next, and the emergence of each new tier offers a qualitatively new way to understand the world. The first tier, *reflexes,* appears at birth. In the the first three to four months of life, infants organize individual reflexes into *actions* (movements they can control). During the next year and a half, babies and toddlers build more and more complex actions, which they eventually reorganize into *representations*—mental symbols for objects, events, and people. As toddlers mature into adolescents, they coordinate personal experiences into complex representations of their world. By the time adolescents reach their teen years, a new kind of skill emerges, allowing the young adult to restructure representations to form a final tier of skills—*abstractions.*

Dynamic skill theory offers an adaptable framework for analyzing the learning process in various contexts. The ten levels that comprise the last three tiers are well suited for characterizing and measuring changes in cognitive (and emotional) learning observed in students. (Reflexes enter the learning picture only rarely; most learning after early infancy involves actions, representations, and abstractions.) Within each tier, people develop through four *levels* of increasing complexity and thus attain mastery of skills at that tier. The first level is a single expression of the understanding that is characteristic of the tier—reflexes, actions, representations, or abstractions. The second level is a coordination of single expressions into *mappings.* At the third level, individuals coordinate two mappings to form a new and more complex skill level—*systems.* The fourth level of a skill demonstrates the ability to coordinate multiple systems into a *system of systems,* and this achievement forms a new structure to begin the next tier: Reflexes form actions, actions form representations, and representations form abstractions.

Most higher education focuses on representations and abstractions. Reading a disciplinary textbook would seemingly guide students from less to more complex representations and then to the abstractions valued by the discipline. However, guiding students along this pathway does not involve moving along a linear progression. They rarely move in a predictable trajectory toward understanding. Teachers generally recognize this fact, which is why they focus on learning styles, multiple intelligences, cooperative learning, and the personal history of students. What is missing for instructors, and what textbooks and lectures do not accommodate, is using the underlying structure of the learning process, which is developmental and cyclical in nature. Students need to build and rebuild an understanding—a process that is driven as much by context as by biology. Although adult students already have in place the biological machinery that allows them to create abstractions, traditional class activities do not automatically lead to abstractions at the appropriate level of complexity. Building a new abstraction requires time, sustained effort, and supporting activities to ground the concept.

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Climbing to Understanding: Learning Takes a While

THE DYNAMIC SKILL THEORY framework provides much more than a scale for analyzing learning. It specifies how cognitive development occurs with variability from moment to moment. People can build relatively stable knowledge, but it requires continual long-term effort. For disciplinary knowledge, which is often not intuitive, it also requires a sustained, supportive educational environment. Cognitive development, especially in the short term, leads to dramatic variations in new levels of knowledge and understanding, not to stable knowledge. In growing new understanding, learners build and rebuild their skills as both the context and their affective states vary. Context and emotion can both support and undermine the stability of the new levels of understanding that students generate as they try to learn new concepts and solve problems.

The idea of a ten-level "ruler" may lull the reader into concluding that the learning process is linear. However, ladders offer only one path among many for moving from where you are to where you want to go and only one perspective for evaluating your progress. A single direct path is not sufficient to describe the enterprise or energy needed to build complex understandings. A more useful metaphor for thinking about the dynamics of learning is the climbing rope structure found on some playgrounds. The structure is organized as a pyramid, and children explore multiple routes toward the top.

If the top of the pyramid symbolizes any one of the disciplinary abstractions that educators want students to learn, the metaphor also suggests several important points about learning and teaching. The base of the pyramid serves as a foundation, which in learning consists of a variety of low-level understandings necessary to support the more complex ideas further up the pyramid. There are many avenues to the top, and when a student is several meters from the top, he or she can occupy various points in space. Different positions may be at the same level of complexity, measuring from bottom to top, but not the same position on the rope structure. Similarly, in learning, students are regularly at the same level of complexity but with different concepts or skills. Dealing with differences between individual learners is one of the toughest issues that teachers face.

A limitation of the pyramid metaphor is its seeming suggestion that any abstraction is supported by only one structure, one that everyone must encounter and climb if they wish to understand ideas such as Newtonian force, universal justice, or postmodernism. Different students will reach the top by building the concepts through different experiences or personal pyramids. The process of learning may culminate in the same abstraction at the top of a pyramid, but it is grounded in diverse activities in variable contexts and cultures.

When students' paths up the pyramid are combined, they form a developmental web, a group of strands of skill construction that are sometimes independent, sometimes intersecting. This constructive web forms an even more helpful metaphor to summarize the skills that individuals need to build, differentiate, and combine in order to understand concepts of force, justice, or perspective. To master abstract concepts from a text or lecture, the challenge students face is reconstruction of high-level representations and abstractions found in the text so that they can control the concepts. Such control requires making sense of the concepts in terms of personal meanings and working them out with personal activities, a process that involves repeated construction and reconstruction.

Representations and Abstractions for Understanding

One key to understanding the content of courses and textbooks—and to devising ways of helping students control those concepts for themselves—is in understanding the nature of representations. At the representational tier, skills focus on a student's re-presenting a concrete understanding of a specific object, event, or person. The student looks at the material and tries to figure out what he or she can re-present—present again to the self or someone else. These representations are the foundation for the more complex abstractions that the discipline values, professors teach, and students aspire to understand. However, students routinely succeed only at re-presenting the concrete representations, and they struggle with the more general, abstract concepts. Teachers and texts can facilitate students' moving to abstractions by building class activities around natural learning processes.

Science instructors commonly find that students can easily recognize Newton's formula for force, $F = m \times a$. One activity that demonstrates this single representational skill is simply identifying the formula as Newton's second law, without demonstrating any additional insight or understanding about the law. Most students quickly master this low-level representational skill. As they move beyond it, they attach specific words to each of the symbols (for example, m = mass, a = acceleration) and solve problems with this formula. With this kind of representational mapping, they relate representations in a single skill. For example, using mapping, a student understands that when a problem provides the mass and acceleration, he or she can calculate the resulting force. However, that is only three numbers related to one another in one calculation.

If Newton's second law is to become more than a concrete representational skill, the curriculum must challenge students' experiences of force, mass, and acceleration so that they can relate these variables in ways beyond what is demanded of them in the calculations of the standard force problems they find in lectures or textbooks. A classroom activity must help students con-

> What are the problems your discipline faces, and how does the text present possible solutions? Students must be able to see this relationship.

nect the understanding to their own experiences. Students build such concepts (first, concrete representations and, later, abstractions) out of their sensorimotor experiences with the world.

The following questions from physics classrooms illustrate ways that students think about their experiences, and reveal the challenges they must overcome in order to understand the concepts as physicists do. The questions are grouped by concepts and experiences.

> Why does the formula use the object's mass instead of its weight? What is the difference? Can my bathroom scale measure both?
>
> Doesn't acceleration mean a change in speed? How can I be accelerating in a curve if my car neither slows down nor speeds up?
>
> How is momentum different from force? If a train is moving at a constant speed, I certainly don't want to be stuck on the tracks when the full force of the train hits me.
>
> When the text says I experience a gravitational force, what does that mean? How do I experience it? I'm not feeling any gravity pulling me as I read this sentence.

While these questions may seem elementary to physicists, they are the questions that students ask when they temporarily put aside the formulas. Each question is a request from the students to help them make sense of the concepts in terms of their experiences, to help them focus on the essential parts of their experiences so that they can learn to use the representations as skilled physicists do.

Representations and abstractions are the tiers of understanding that are shared in the discourse of the discipline. Underlying both tiers is an important foundation—the individual's own relevant activities—that is often neglected in introductory college courses. It is from personal experiences that students build representations and eventually abstractions for force, mass, and acceleration. Textbook authors and lecturers seldom consider how the representations they present can be tied to students' sensorimotor experiences.

The textbook author and the lecturer are in peril when they assume that the concepts of their discipline are transparent to students and when they do not help students build concepts with the support of personally relevant activities. Sophisticated students learn to ignore their experiences and memorize the representations they find in the text and in class, but this compromise results in an unstable pyramid. The base of this pyramid cannot support building the skill to high levels.

The top of any conceptual pyramid can remain out of many students' reach for several reasons. First, students may lack sufficient experiences to build the concepts from the sensorimotor ground up, which reduces the area of the knowledge base and thus the eventual height of the pyramid that the base can support. Given a reduced base, students cannot construct understandings beyond a certain level of complexity. For example, to understand forces the way physicists do, students must confront experiences that highlight conflicts between their own everyday understandings of force and those of physicists. To keep a stalled car moving, students might say they must continue to exert a "force." This explanation is far removed from students' experience with actual cars and from the physics textbook's explanation, which focuses on frictionless states (such as in outer space) to emphasize that a body in motion remains in motion without any additional force.

One tool to facilitate building of understanding is contextual support to help students work out key concepts and skills. Although a textbook can provide scaffolding, it is not easily targeted to individual understanding and probably has not been tested for its effectiveness as an aid to student learning. Typically, texts do not address students' misconceptions, even when research has shown them to be nearly universal. Successfully challenging students' misconceptions requires starting with their experiences with the concept. Students can further benefit from instructors' providing specific supports for knowledge—for example, by demonstrating how to navigate a structure for a key concept or pointing toward safer ways to climb the knowledge pyramid and toward alternative routes that may require less energy. As skills become more complex, support becomes even more helpful, because the number of possible routes for constructing the complex skill increase and attempts to re-enact the skill must be repeated for each route.

Any successful consolidation of a skill requires practice. A student learning Newton's second law must repeatedly grapple with the elements of the law that lead to experiences that reorganize personal representations of force, mass, and acceleration. The process of building and rebuilding to create a general understanding is neither quick nor easy.

How Can Students Learn from Textbooks and Lectures?

GIVEN THE DYNAMIC WAY that students learn and the importance of their own experiences as a foundation for learning, traditional pedagogy's reliance on the textbook and lecture is problematic. The textbook and associated lectures tend to provide an encyclopedia of facts and concepts presented from the author's perspective on the discipline. In some science texts, there is no story at all, but a compendium of diverse facts, concepts, principles, and examples. Many high school and college students view and use science textbooks as encyclopedias. With the shift from high school to college, textbooks only become more difficult conceptually. One result seems to be that many students view learning as collecting facts rather than understanding the concepts of a discipline.

Current pedagogy mostly leaves students to struggle with textbooks and lectures in order to figure out how to build their own understanding. That is one of the central reasons that so many students never succeed in understanding. Authors of the best textbooks choose a story line that makes sense to them, one that has been shaped by their experience in the discipline. They may be able to make some assumptions about which experiences are most likely shared by students, but it is hard to predict what sense students make of those experiences and how they coordinate them with other experiences of which the author has no knowledge. At its best, however, the story line helps some students and teachers to create knowledge by working with the material in textbooks and lectures.

Good classes can facilitate this process, but students' experiences and activities can easily be overlooked in the design of lectures. The structure of the textbook can lead instructors to create lectures that follow the text's story line without considering students' ways of understanding it. Usually, instructors allow students to ask questions, but still the direction of the lecture is predetermined, and whether the question is satisfactorily answered and understood or not, the instructor will eventually terminate the dialogue and continue. As students listen, they construct views that may or may not be correct. Instructors watching the clock and agenda, as well as listening to students, will find it difficult to tell whether a student's understanding is correct, especially if students are sufficiently vague.

More vexing are students' incorrect answers based on (mis)understandings that are difficult to change. The creation of these understandings may represent considerable work, similar to a child's effort in climbing a playground pyramid. Students (like people in general) resist giving up their ideas unless they can spend the time and effort needed to build an alternative based on their activities. General knowledge does not come from memorizing a lecture or text but from working with concepts in action and thought. From the student's perspective, a clearly worded text or succinct lecture does not constitute a strong enough argument to change a view, because neither the text nor the lecture sufficiently challenges the sensorimotor or action experiences that students are using to create their own representations.

An important role for instructors and textbooks is to direct students' attention to concepts that are central to the discipline, but the concepts need to be linked to an understandable goal related to activities. Students do not always see what they need to do to create their own understanding or how the text can support their understanding. Since they are not sure what the goals are (other than getting a good grade) or what skill they are attempting to use, the support they might extract from the text often remains inert. Students often spend long hours on homework assignments and classroom worksheets without any significant gain in understanding.

In Zheng Yan and Kurt Fischer's study of a university course known for its success in teaching statistics, only 40 percent of the students showed clear progress in using key concepts in analyzing data. For less successful courses, in our experience, the percentage can approach zero. The problem is that assignments, lessons, and lectures often represent solutions to problems that students have not internalized or cannot appreciate. Skills and concepts without meaningful goals leave students to try to memorize procedures they do not have a foundation for applying in new contexts. This problem helps explain what research (as reviewed, for example, by Gavriel Salomon and David Perkins) has demonstrated repeatedly: there is typically little transfer of skills from the classroom to new situations.

Possible Solutions

One approach to improving the troubling situation of students who are unable to apply their skills outside the classroom is to change instruction to support activity-based learning. Seminars, science laboratories, and professional schools frequently place activities at the center of their pedagogy. Law classes debate points of the law. Medical students work with real or virtual patients to diagnose and treat illnesses. Molecular biologists debate laboratory procedures for research studies, conduct the studies, and then debate explanations for the results (which commonly are different from predictions).

A team of educator-researchers—Kurt Fischer, Howard Gardner, and a group of doctoral students—have been devising a new approach to educating education students that combines activity-based classes with use of authoritative texts and lectures to support activities and debates. Lectures are mostly not given in the classroom but rather put on the Web in what we call *video chapters,* which students can watch and listen to in a way similar to how they read chapters. (See http://my.gse.harvard.edu/icb/icb.do?course=gse-ht100 for a description of one such course.) Students also read important papers, including chapters from textbooks. What happens in the classroom, however, is both activities based on those materials and debate and dialogue about the readings and lectures. For example, students debate the analysis of cognitive development offered by Piaget and by Vygotsky. They also analyze a mother-child interaction in terms of the emotions that shape the interaction and support structures the mother provides for the child in performing tasks. We are in the process of assessing whether this approach succeeds in creating general knowledge that goes beyond memorizing texts and lectures.

In the following paragraphs, we offer suggestions that may be helpful for instructors who want to help students build knowledge based on their own experiences and activities. These ideas, which come mostly from science teaching, illustrate the kind of work needed to support the learning representations and abstractions prized in many courses and textbooks.

• ***Find out what kinds of representations students are using to make sense of the problems they face in your courses.*** Assessing their initial understanding helps you understand where the students are starting in the subject area. From this, you can consider how to support them in developing what you would like them to understand.

• ***What are the problems your discipline faces, and how does the text present possible solutions?*** Students must be able to see this relationship. Books and instructors should seek ways to capture the essence of the problems in the discipline (which generated the solutions that students should come to understand). Students can then experience the problems and begin to learn the steps toward solutions that the discipline has taken.

• ***What are the metaphors that the discipline uses to make sense of the problems and concepts?*** Texts and instructors should engage students in analyzing the implications, limits, advantages, and disadvantages of the metaphors. In this article, for example, we discouraged readers from using a ladder to think of development and learning. We used an alternative metaphor of a playground pyramid to highlight how students must repeatedly climb toward a concept, building complexity as they move higher. While this metaphor highlights levels of complexity as well as the need for sufficient support to build complex understandings, it does not easily capture the diversity of contexts that students might experience that could lead to the same abstraction. So we offered the reader the opportunity to grapple with a second metaphor—the web of paths for building skills or climbing a pyramid.

• ***Seek out the anomalies of the discipline as a means to encourage students to share their experiences and explore how they can make sense of the problem that an anomaly poses.*** For example, the concept of force becomes an anomaly in physics because the word *force* is used in so many different ways and there are so many different experiences related to forces that students may be trying to understand.

• ***Consider what kind of sensorimotor (or action) understandings might serve as a foundation for the representations and abstractions students will encounter in your course and the text.*** What are the essential experiences for understanding force, justice, or postmodernism? For example, will experiences of segregation, sacrifice, or empathy promote understanding of universal justice? Will experiences of cultural ostracism or barriers to self-fulfillment relate to understanding of postmodern analyses of perspective?

• ***Ask students to discuss with one another how they are making sense of the problems posed in class and then have them share those understandings with the class and you.*** This step allows students to consider how they are making sense of representations used in class and the textbook and whether these understandings are helpful and accurate. The instructor can use these discussions to gauge whether students understand enough to support movement to the next level of representation or abstraction.

The textbook and, to some degree, the lecture represent a culmination for authors and teachers who have worked for many years to understand and re-present those ideas. Given the length of time and the efforts that authors and teachers have invested, they should take a more modest view of what students can re-present in a semester or a school year. This is particularly true in intro-

> Students do not always see what they need to do to create their own understanding.

ductory courses. To have students show real learning of concepts, not just memorization and recitation, instructors need to consider how many pyramids students can climb and re-climb multiple times in a semester in order to build a concept or skill. It is useful to realize that students can learn to recognize many relevant pyramids (each supporting a concept prized by the discipline), but the number of pyramids and the height (or level) students can reach in each of them will be limited in any course. Mastering a field requires years of work, not one course.

Conclusion

THE PEDAGOGICAL CHALLENGE in higher education is to help students recognize the goals of a discipline, identify its central problems, and find strategies for building the representations and abstractions of the discipline. As Wilber Jackman observed about students in 1894, "The mechanics of the lever is only so much 'stuff and nonsense' to him, until he finds that this knowledge will render possible an economy of his energy, and thereby immensely prolong his mortal existence." In education, enormous energy has been invested over the last two centuries to create "better" textbooks and lectures to support students' learning. However, the effectiveness of this support is compromised when the active nature of learning is overlooked and when the problems students find in textbooks and lectures offer goals they neither understand nor appreciate.

The risk of continued domination of pedagogy by textbooks and lectures is that students will not receive the time and support they need to build the sophisticated representations and abstractions of the discipline. Current prominent practices, perhaps especially in science, can entrap instructors in a framework that encourages the use of carefully scripted texts, laboratories, and lectures and minimizes students' building of personally meaningful representations and abstractions. With these practices, yet another generation of students would be expected to internalize goals that most of them do not comprehend and to master content that neither they nor most students in previous generations could understand.

The dynamic skill theory described in this article provides tools and concepts for analyzing how students move at diverse rates along various pathways as they learn a subject. This contrasts with the linear view of education that is assumed by most textbooks and lectures and that is prominent in our society, which expects progress to move in a linear and upward fashion. Texts as well as instructors must face the dynamic nature of learning. Students progress at different rates, along different pathways, and their rates and pathways vary with changes in context, support, and motivation.

To establish a more productive relationship between student thinking and disciplinary knowledge, instructors should consider how to help students build their own understanding of the representations and abstractions that the textbook and lecture have carefully stored for current and future generations. Instructors will have to resist simply retelling the text's story or reciting their own and instead look for opportunities to help students create personal experiences that make sense of the intellectual treasures that earlier generations have struggled to understand and preserve, building understanding by creating their own pathways.

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Additional Resource

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