Deeper Learning Towards What?:
The Nature of Deep Understanding

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Educators hear a lot about deeper learning and how important it is to help students get beyond superficial knowledge in order to develop robust understandings that will serve them well in the world beyond school. It is certainly important for developing Next Level Learners who have the skills to thrive in a turbulent and uncertain world. But often "deeper learning" is ambiguously described as pedagogies focused on more active processing. Active processing in and of itself is a good thing as it invites thoughtful engagement in learning. However, the question, "Towards what end?", needs to be addressed.

In the framework of Teaching for Understanding (TfU),[1] the mission of education is defined by the carefully selected Understanding Goals that educators identify. These differ from objectives in that the understandings that students are intended to reach are explicitly articulated. For instance, an objective might say, "Students will understand the role that perspectives play in history." In contrast, an understanding goal might say, "Students will understand that multiple perspectives contribute to a richer conception of historical events." One could argue, quite simply, that deeper in terms of the given understanding goals is necessarily better and teaches may have a clear sense of what that means for particular concepts.

However, it still behooves us to ask about the nature of deep understanding, how it is characterized and what features it has. [2] Next Level Learners need to develop understanding that is both deep and flexible. In a later article in this series, we will consider flexible understanding. Here, we focus on deep understanding. What does deeper understanding, in general, look like and how can one judge whether a particular pedagogy is helping them to get there? Fortunately, a rich literature on the nature of expertise and on the cognitive science of learning offers some answers.[3] Below I discuss seven ways to recognize deep understanding and offer examples of implications for teaching and learning.

1. **Knowledge is connected to other knowledge and systems aspects of the knowledge are understood.** The concepts are viewed within a web of related concepts. One knows how the concepts fit within the broader landscape of knowledge. One also has multiple paths to the knowledge so that if some neural pathways decay, others can lead back to it (for instance, if an algorithm is forgotten, one can derive it conceptually or if the exact name of a component slips from memory, it may be recovered by considering the role it plays with others). One can also think about the concepts and how they interact within a system. Consider deep knowledge of gardening. As opposed to choosing what to plant in an isolated way as a novice might, someone with deep knowledge would consider which plants are adjacent to each other and how the soil, light, and water needs of each interact. They would take care not to plant allelopathic plants, plants that put chemicals into the soil to suppress others growing near them, close to others in their garden.

The choices of a novice gardener fit with what we know from the learning and cognitive sciences about the conceptual structures that learners hold when they do not have deep knowledge of a topic. Research has shown that often novices hold isolated pieces of knowledge that are coherent within each piece,[4] but that conflict with each other, whereas experts would view the pieces as one broader, related conception. For instance, children might see their coats as a source of heat that keeps them warm. This view might be held alongside a separate belief that oven mitts work as a barrier to protect people's hands from heat when taking something hot out of the oven. Those with deep understanding would view both as forms of insulation that slow down the process of thermal equilibrium and would see the body as the source of the heat when wearing a coat.

What are some ways to support the building of connected knowledge in practice? Teachers can help students to connect to prior knowledge through a "Connect Back" move or encourage learners to keep the concepts in mind as they find out about new concepts in a type of "Connect Forward" step.[5] Learners can build concept maps of how new concept fit with other concepts.[6] Beyond this, a half century of research on how children build their theories of the world[7] underscores the importance of examining their current, isolated conceptions, analyzing what contributes to them, and helping them to build more powerful and unified conceptions. It can be difficult to build systems concepts without support for the inherent cognitive load. Simulations such as those developed by the PhET group[8] (see the link in the endnotes) can support students in thinking about the systems concepts in dynamics ways without overloading working memory.

2. **Representative cases and edge cases of the knowledge are understood.** Deep understanding allows one to detect typical cases of concepts and to know where the edges or boundaries are. One knows the "essence" or "center of gravity" of the concepts as well as how far they can be stretched. Knowing the essence enables one to extract its essential features—the characteristics that it must have in order to fit the definition.

Stop reading for a moment and imagine a chair. I am guessing that many of you pictured an object with a seat, straight back, and four legs. For many of us, that constitutes the most representational case of a chair. But what about a director's chair that folds out with a cloth-like seat or a beanbag chair that has no discernible legs at all? At what point is a chair no longer a chair? What features or sets of features must it have to be a chair? In short, what is its spine? When you have deep understanding of a concept, you can think about it in this way. Think about a policy brief, a poem, or a scientific paper. What features must each have? At what point has the author strayed too far? A deep understanding of levers enables one to notice cases and non-cases of levers everywhere. We see levers in seesaws. What about door handles? What if we use it metaphorically as in a constitutional lever? What features, metaphorically, must it have?

What are some ways to support the understanding of representative cases and edge cases in practice? I often engage my students in building deeper understanding of concepts through a process called prototyping. The term "prototyping" is commonly used now in relation to the maker movement and developing a design. In psychology, it has long referred to something that serves as a standard in the sense of the most complete notion of something in that it has all the expected qualities and characteristics (the four-legged version of a chair). In cognitive science, it refers to graded categorization in which some exemplars of a category are more central to the concept than others. Some category members are viewed as more pure exemplars whereas others are at the edges of the main concept (edge cases). I ask students to create a circle and put the most representative exemplars of a concept in the center and to figure out how far from the center (if in the circle at all) to others. It pushes their attention towards the deepest features, engages them in active processing as they discuss each example, and results in deeper understanding. I have used this process to examine exemplars in K-12 classrooms to develop deeper understanding of concepts related to simple machines, air pressure, and density-driven phenomena in science and cases of stereotype threat, gerrymandering, and poetic justice in humanities classes. With teachers in graduate school, we have focused on concepts related to teaching and learning such as conceptual change, problem-based learning, and discrepant events.

3. **The knowledge can be distinguished from closely related concepts.** Deep understanding includes knowing how concepts are similar and different from each other. When gaining understanding, it is common to see similarities between closely related concepts, but still be unclear about the boundaries and the distinctions between them. Deepening understanding includes clarifying these. Noticing distinctions deepens knowledge and understanding. The ability to discern differences reflects and builds deep understanding. For instance, careful observation in the biological sciences often advances theory. Darwin's careful analysis of bird beaks enabled him to evolve his theory of natural selection, environmental fit, and the ability to adapt to new environments within his work on the nature of evolution.

   What are some ways to support the understanding of distinctions between closely related concepts in practice? Contrasting cases is an approach developed by Daniel Schwartz and colleagues[9] that involves careful analysis of a seemingly similar set of examples to find the distinctions between them. It can lead to new insights about the underlying principles involved in the phenomenon just as it did in the case of Darwin discussed above. Often, people use contrasting cases with visual or other perceptual stimuli, as in the differences between bird beaks or between two musical compositions. However, contrasting cases can be a powerful way to come to a deeper understanding of more abstract concepts. For example, I ask my graduate students to contrast concepts such as constructivism and conceptual change, for while there are many similarities that would make them easy to conflate, there are important differences for those who understand them deeply. There are many concepts in K-12 in which contrasting seemingly similar cases would drive deeper understanding. For instance, one might contrast metaphor, analogy, and simile or animals that appear similar in their features. My colleague, Jon Star, uses this approach for developing deep understanding of math algorithms. HS teacher Tore Kapstad has students contrast religions that seem similar on the surface in his unit on "Are the World's Religions More Similar or Different?" The unit uses a generative tension at the center to drive examination of contrasting cases without necessarily expecting students to come down on one side or the other at the end.

4. **The structure of the knowledge is understood.** With deep understanding, one can discern and consider the underlying structure of concepts--the inherent principles and its exceptions (even in the presence of significant noise/distraction).[10] Grasping the deep structure makes it easier to understand related concepts and procedures.

   Teachers often talk about procedural knowledge ("knowing how" such as in math equations, following a recipe, programming a computer, or writing Haiku) and conceptual knowledge ("knowing what" such as in mental models of how sinking and floating works or what accounts for a powerful and persuasive essay). In my work with teachers, I encourage them to focus on structural knowledge in addition to procedural and conceptual knowledge.[11] By this, I mean how the domain level principles are structured and the unifying theories and framing that account for them. I call this "Getting to the Bones." Structural knowledge includes such things as the underlying causal patterns, how the concepts fit in taxonomic categorizations, and underlying principles that explain them.[12] For instance, understanding the Albedo Effect in climate change involves, at its core, understanding forms of causality related to feedback loops and escalation. Knowing how metals behave connects to its atomic and molecular structure making it possible to predict how it will behave in different conditions.

Research shows that the underlying structural knowledge that experts hold often differs from that of novices. When learning new concepts, novices often take the factual aspects of knowledge taught to them and distort it to fit the structures that they already hold. For instance, learners revert to consumer-source models of how electrical circuits work instead of higher-level models that are cyclic and involve density-driven differentials in electrons and protons. Or they assume that when they suck on a straw, they create a vacuum that makes the liquid rise in the straw in a simple linear way—ignoring the role of ambient air pressure. [13]

What are some ways to support the building of structural knowledge in practice? One of the most important things for teachers to do is to analyze the concepts that they are attempting to teach to identify the inherent structural knowledge and then to develop ways to reveal it to students. In the straw example above, I push students' attention to the role of the ambient air pressure by limiting the amount of air that can enter the system in a manner similar to how a juice box eventually flattens out and one must allow more air to enter in order to finish the juice.[14] This helps students to view the underlying structural knowledge as being a pressure differential described by relational causality instead of linear causality. Another way to support students in understanding the deep structures is to help them to think about different ways that the knowledge might be structured and to consider which makes the most sense to them. One of my former graduate students, Shawn Lavoie, did this in a unit that he developed to help students to think about the meaning of the "common good." He shared a list of different ways of conceptualizing the common good for students to consider and then engaged them in readings and experiences to actively process the different conceptions.

5. **In the case of designed knowledge, the motivations and design principles are understood.** One understands the design of constructs or concepts and the circumstances surrounding it. Designed knowledge exists all around us. Some types of knowledge are designed to meet certain needs, for instance, numbers and maps. Frameworks (thinking, problem-solving, and organizational for example) are also like this. Others evolved in response to constructive discontents and may be as simple as designing a better recipe or as complex as designing an entire field of study. For example, the field of the "learning sciences" was developed as a response to the need for a discipline that studies learning in applied contexts, over long periods of time, and in ways that reflect the complexity of the environments that learners are embedded in. Deep understanding entails knowing why something is a certain way, what purposes it serves, and what trade-offs were made in its design.

   What are some ways to support the understanding of designed knowledge in practice? Look for ways to engage your students in the thinking behind the resulting product/knowledge. This can be done by inviting them into the history of the evolution of the knowledge. For instance, I had my fifth graders attempt to flatten a grapefruit planet as a way to understand the many distortions that result and inherent challenges of representing a round object in two dimensions. We then studied the many different maps available—the common Mercator projection, the Equal Area Peter's projection, Polar projections and the Icosahedral projection of Buckminster Fuller amongst others. It made apparent the motivations and design choices of the cartographers. Some maps accurately portray trade routes while, others distort the poles as a trade-off for better representation of land masses closer to the equator. A polar projection can be useful in airline travel. Similarly, when studying different number bases, I invited my students to solve the problem of trying to keep track of a very large herd of sheep without the benefit of the numbers that they were taught. Their solutions ranged from a lot of pebbles in pockets that quickly became too heavy to realizing why some humans evolved base ten and others evolved base twenty, to the value of place value and zero as a place holder when you only have ten fingers, and so forth. They learned a lot about other base systems, but they also learned the design assumptions behind the numbers that they had been using and taking for granted since early childhood.

Another way to teach about the design of knowledge is to have them analyze it. David Perkins wrote a gem of a book in the 1980s called "Knowledge as Design."[15] It asks four questions about the design of knowledge that helps one to dive into why it is the way that it is--inviting deeper understanding: 1. What is its purpose? 2. What is its structure? 3. What are model cases? 4. What are the arguments that explain and evaluate it? I used these questions with fourth through sixth graders to think about various designs around them. I added a question about what impossible or bad cases of the design would look like. Students drew pencils with the graphite along the side of the pencil or a pencil with an eraser that followed along right behind the graphite. These designs go a long way towards understanding why pencils are designed the way that they are!

6. **The disciplinary origins of the knowledge are understood.** Deep understanding requires knowing how the knowledge was generated and with what disciplinary assumptions and lenses. This can impact whether one believes certain interpretations to be valid, findings to be reliable, and when uncertainty or faith are inherent to, or part of, the conceptual origins. This is often referred to as epistemic knowledge. Epistemic knowledge in history might include the principle that objectivity is achieved through the careful documentation of varied perspectives on an historical event—in a sense, the counterintuitive notion that increasing numbers of varied subjective accounts results in greater objectivity. Epistemic knowledge in science includes principles such as the importance of testing the reliability of findings, that the ability to generalize findings drops off as levels of similarity between study participants and those to whom one is generalizing drop off. Such disciplinary knowledge can be thought of as a special case of design. Understanding the disciplinary ways of knowing also involves understanding and being able to use the thinking routines or moves that are central to the discipline. For examples, this includes moves such as Control of Variables (COV) in experimental science, Gap Analysis in ecosystems science, and forms of perspective-taking in history.

Distinctions in how novices and experts understand the epistemological underpinning of knowledge are often apparent in public discourse and can be problematic for an informed citizenry. For instance, scientists present sources of uncertainty in their predictions related to climate change as part of how scientific inquiry works and yet the public can misinterpret this to mean that entire phenomenon to climate science is uncertain.[16] It also can be too easy to define the disciplines in contradiction to each other rather than to realize the many sources of overlap in their disciplinary ways of knowing. For instance, the arts often use analogy or juxtaposition to give voice to different perspectives. In situ science also often takes creative leaps in imagining possibilities through tools such as analogy and juxtaposition.[17]

What are some ways to support the understanding of the disciplinary origins of knowledge in practice? Engaging students in regular conversation about how knowledge is generated should be an essential aspect of instruction. In the U.S., the Next Generation Science Standards (NGSS)[18] include a strand called the Science and Engineering Practices (SEPs) which are helpful in this direction. However, the teaching of these practices should explicitly include the rationale for why the practices are core to the discipline; the underlying assumptions help people to understand the nature of the knowledge, the sources of uncertainty, and where is might be powerful as well as when it might break down or not be helpful. My colleagues and I developed a curriculum unit with an immersive computer environment called EcoXPT which is available for free download. As part of this work, we helped secondary school students to learn a disciplinary approach that ecosystems scientists employ called a “Body of Evidence Approach” given the complex environments in which they work and the difficulties conducting controlled experiments.[19]

7. **The status of the concepts is understood.** Deep understanding involves knowing how the concepts are currently viewed in the domain—their current status. Those with deep domain knowledge understand the evolution of concepts in their field and why various shifts in knowledge took place. This helps them to frame issues that arise and how to handle them. Expert builders hold knowledge of how procedures for insulating homes have changed over time and what is currently considered best practice. Experts working with families dealing with autism know that while it was once believed that autism developed in response to mothers who were cold and distant, researchers were likely observing the result of shared genetics between parents and children. How understandings evolve and change relates to how knowledge develops. It is also essential to helping learners to realize that knowledge likely will continue to evolve and change over time and that having deep understanding in a domain requires keeping up with new knowledge.

   What are some ways to support the understanding of the status of concepts? It is not uncommon to teach historical perspectives; it is less common to help students *to see them as* historical perspectives (unless it is something dramatic and unchanging such as the shift from a flat to spherical earth) and they are sometimes left not understanding the status of the concepts. Look for ways to invite your students into the shifts and the problems that they addressed. Also help them to see that sometimes there are more recent conceptions, but we still use earlier ones for certain ideas. This is the case with Newtonian and Einsteinian physics. Engage them in discussion about the status of the concepts and how to connects to how the discipline works. I tell my science students that science is a process of trading up for more powerful explanatory models and that revising and improving upon explanation is key to the work of the discipline. Historical explanation is revised as greater and more diverse perspectives are brought to bear.

These seven characteristics are well supported by the research literature in cognitive science and the learning sciences. They are important guideposts for me as an educator. They let me know that the pedagogies for deeper learning that I engage my students in do, indeed, result in deeper understandings that will serve them well in their futures.

About the Next Level Lab:

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[11] Some researchers consider structural knowledge to be an aspect of conceptual knowledge. I have argued (Grotzer, 2002) that a specific focus on it ensures that it will be attended to.

[12] Grotzer, 2002.

[13] As reviewed in Grotzer, T.A. (2004). Putting science within reach: Addressing patterns of thinking that limit science learning. Principal Leadership, October 2004 5(2) 217-221.

[14] See a video of this activity at: http://www.causalpatterns.org/recast/general_examples.php

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[16] And as documented by Oreskes and Conway in Merchants of Doubt (Oreskes, N. & Conway, E.M. (2019). Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Climate Change. Bloomsbury Publications), has been exploited by certain industries towards their own goals.

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