The 7 trans-disciplinary habits of mind: Extending the TPACK framework towards 21st Century Learning

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Abstract

In this article we examine the need for fostering transformative learning, emphasizing the roles that trans-disciplinary thinking and recent technologies can play in creating the transformative teaching and learning of the 21st century. We introduce the Technological, Pedagogical Content Knowledge (TPACK) framework as a starting point for discussing the special kinds of knowledge, skills, and understanding that teachers require in order to become effective classroom mediators of transformative learning experiences. Within this framework, we propose seven cognitive tools needed for success in the new millennium, and describe examples of how teachers can repurpose digital technologies to use these cognitive tools. We explore the implications for research and practice.

> Today, the defining skills of the previous era—the "left brain" capabilities that powered the Information Age—are necessary but no longer sufficient. And the capabilities we once disdained or thought frivolous—the "right brain" qualities of inventiveness, empathy, joyfulness, and meaning—increasingly will determine who flourishes and who flounders. (Pink, 2005, p. 3).

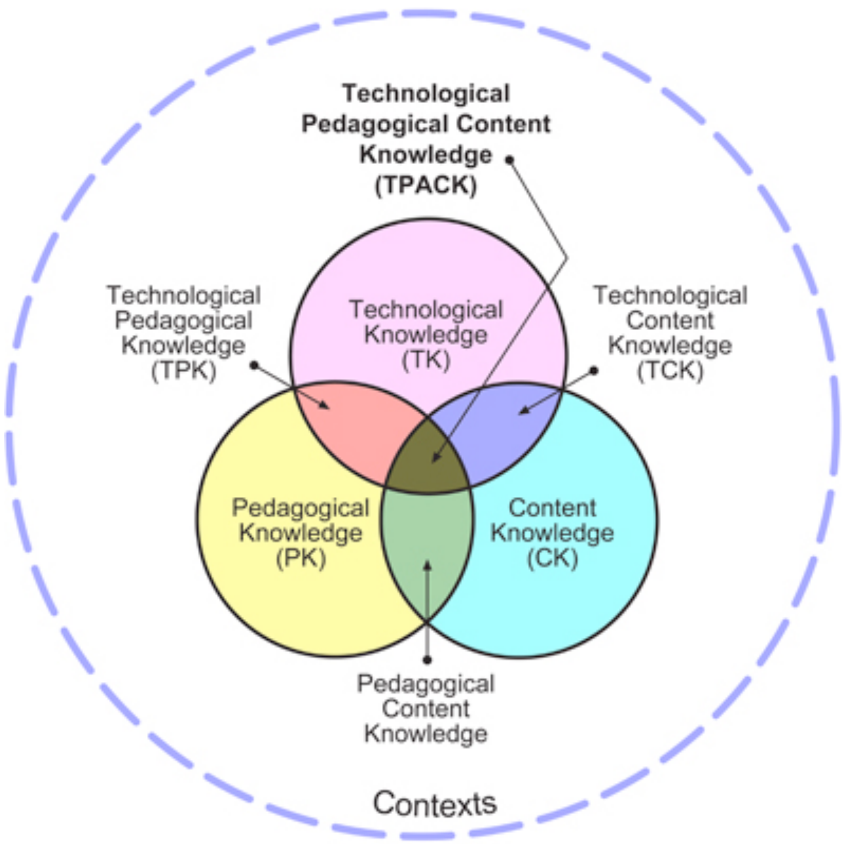
The role of technology in learning

We live in exponential times – digital technologies have already transformed the way we work and play. From cell phones to websites, from YouTube videos to multiplayer games like World of Warcraft, technology is fundamentally changing how we interact with information and with each other. The future promises more of the same, given the increasing pace of technological innovation.

This rapid rate of change is a challenge for educators, as technologies become obsolete as quickly as they arrive. There is increased pressure on teachers to learn new ways to incorporate technology into their teaching. Technology integration however, still finds disappointing levels of penetration and success (Barron, Kemker, Harmes & Kalaydjian, 2003; Cuban, Kirkpatrick & Peck, 2001; Bauer & Kenton, 2005; Ertmer, 2005; Frank, Zhao & Boreman, 2004; Gulbahar, 2007; Keengwe, Onchwari & Wachira, 2008). For effective integration, teachers must know more than the technical aspects of technology, and must understand its affordances and constraints both for representing content and identifying pertinent teaching approaches (Harris, Mishra & Koehler. 2009). Recently, the *Technological Pedagogical Content Knowledge* (TPACK) framework (American Association of Colleges of Teacher Education, 2008; Koehler & Mishra; 2008; Mishra & Koehler, 2006) has been offered as an integrated framework for teacher knowledge for effective technology integration.

The TPACK framework acknowledges that teaching is a highly complicated practice using flexible and integrated knowledge (Shulman, 1986, 1987). Teachers practice in a complex, dynamic environment (Leinhardt & Greeno, 1986; Spiro, Coulson, Feltovich, & Anderson, 1988; Spiro, Feltovich, Jacobson & Coulson, 1991) and must integrate knowledge of student learning, knowledge of the subject matter, and increasingly, knowledge of technology. At the intersection of pedagogy, content, and technology, is the specialized brand of teacher knowledge represented by TPACK.

The TPACK framework describes these components as being a critical synthesis of knowledge used by the most effective teachers. *Content Knowledge (CK)* refers to the knowledge about the subject matter, such as 8th grade mathematics, or 5th grade science (though we shall complicate this straightforward conceptualization later in this article). *Pedagogical Knowledge (PK)* refers to knowledge about the processes and practices or methods of teaching. It includes classroom management skills, teaching strategies, evaluation techniques, and the nature of target audience. *Technology Knowledge (TK)* refers to knowledge about both the standard technologies and more advanced technologies. (Mishra & Koehler, 2006; Mishra & Koehler, 2008; Koehler & Mishra, 2008; Mishra & Koehler, 2009; Koehler & Mishra, 2009; Harris, Mishra & Koehler, 2009).



The TPACK Framework (source: www.tpack.org)

These three core constructs (diagrammed above) interact in important ways. At their heart is *Technological Pedagogical Content Knowledge* (TPACK), which emerges from the interaction of content, pedagogy, and technology knowledge. *The TPACK framework suggests that quality teaching requires a nuanced understanding of the complex interplays between three key sources of knowledge: technology, pedagogy, and content, and addresses how they play out in specific contexts* (Mishra & Koehler, 2006; Koehler & Mishra, 2008; 2009). It is also important to note that the TPACK framework offers no specific directives about *what* content to teach (science or music), *which* pedagogical approaches are useful (didactic or constructivistic), and *what* kinds of technologies to use in teaching (digital or analog). Thus, given the changing world we live it, it becomes critical for us to ask ourselves what it is that today's students need to know to succeed (i.e. understand the "C" in the TPACK framework). Once we identify these larger purposes and goals the TPACK framework helps us consider *how* to achieve them via technological/pedagogical solutions.

Living and learning in a changing world, an overview and a critique

The rapid evolution of technology in the 21st century calls for a new form of learning, one that is receptive to our continually changing world (Florida, 2002). Recently there have been a spate of books and reports that criticize the current goals and practices of schooling (Keengwe, Onchwari & Wachira, 2008; Kozma, 2003, 2009; Zhao, 2009). These authors argue that schooling needs to be fundamentally reconfigured to emphasize higher order cognitive processes such as critical thinking, creative problem solving, curiosity, and adaptability.

Most of these recommendations, however, do not even mention content, and in the rare cases that they do, it is only in terms of traditional disciplinary content areas, such as language arts, mathematics, and science. Standard disciplinary structures, around which school-curricula have been constructed, may not be as useful as they once were. Disciplinary knowledge is shifting beneath our feet (Koehler & Mishra, 2008). Recommendations for the future of learning emphasize the importance of being able to creatively move across multiple disciplines, to cross-pollinate ideas between domains.

Furthermore, current research and theory on creativity suggests that creativity is *both* domain -general and domain- specific. As Plucker and Zabelina, (2009) write:

> A person who deals with domain general techniques and approaches to creativity will never scratch the surface of a problem, yet someone who focuses too tightly for long periods of time on a particular task is likely to experience functional

> fixedness…. [The] optimal condition for creative production is a flexible position somewhere between generality and specificity… with the individual moving between positions as the task or problem of the moment dictates (p. 9).

This means that, creativity is intimately tied to cultures of disciplines, ways of knowing and being that are constrained by specific fields of study *as well as* broader ways of thinking that cut across different disciplinary frameworks.

Transformative learning and Trans-disciplinary learning

As must be obvious, preparing students for 21st century learning presents a challenge to educators, and requires us to rethink the goals of education. *Transformative Learning Theory* (Mezirow, 1991; 1995; 2000) addresses this challenge by requiring learners to rethink prior knowledge, or even drastically transform their approach to an idea. Transformative learning theory expresses the universal challenge of teaching and learning as a critical kind of knowledge transformation – a "paradigm shift" or a perspective transformation, in which a renovation of existing knowledge structures occurs (McGonigal, 2005).

We suggest trans-disciplinary knowledge *that both emerges from disciplinary practices and transcends them, is critical.* Trans-disciplinary knowledge helps students move beyond looking for one "correct" solution, towards an approach that integrates different solutions, viewpoints, or perspectives.

Trans-disciplinary approaches eschew traditional distinctions between art and science, applied and pure knowledge. This approach seeks to find commonalities between strategies and habits of thought used by creative individuals in any discipline. Our work in this area builds on prior conceptual work done in this area by Root-Bernstein (1996, 1999), which studied the value of trans-disciplinary learning through both historical and empirical research. This led to their assertion that creative scientists and artists generally use a key set of cognitive skills that cut across disciplinary boundaries. As they write:

> … at the level of the creative process, scientists, artists, mathematicians, composers, writers, and sculptors use…what we call "tools for thinking," including

> emotional feelings, visual images, bodily sensations, reproducible patterns, and analogies. And all imaginative thinkers learn to translate ideas generated by these subjective thinking tools into public languages to express their insights, which can then give rise to new ideas in others' minds. [11]

Based on their key "thinking tools" we propose seven key trans-disciplinary tools (or cognitive skills), which encapsulate how creative minds think effectively across a range of domains[1]. These seven cognitive tools are: *perceiving, patterning, abstracting, embodied thinking, modeling, play, and synthesizing.* Each of these is described in greater detail below. We assert that these "tools," or habits of mind, comprise a framework for trans-disciplinary creativity and can serve as the basis for the kinds of curricula that are essential for the "conceptual age" (Gardner, 2007; Pink, 2005).

Connecting TPACK to trans-disciplinary cognitive tools

We began this article with a description of the TPACK framework and noted that it did not specify explicit pedagogical and content goals. The preceding sections developed an argument for transformational learning of a specific kind—moving from standard disciplinary structures to trans-disciplinarity. Consistent with the TPACK framework, this change in how we conceptualize content has implications for both pedagogy *and* technology. Here we describe each cognitive tool and offer examples of how each can be instantiated in a classroom context through appropriate, TPACK driven uses of technology.

Perceiving

The cognitive tool of perception is critical to both the arts and the sciences. This is a two-layered process, requiring both *observing* and *imaging*. Observing is a finely tuned skill based on intent focus on, attention to, and curiosity about information gathered through the five senses. For example, bacteriologists use their sense of smell to observe bacteria, or an ornithologist might identify bird species by sound. Imaging calls for the ability to

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[1] The Root-Bernstein's list 13 cognitive tools in their book. We have modified this list to come up with seven that we consider to be particularly significant.

evoke or bring to mind the impressions/sensations we observe, without the presence of external stimuli. Artists, scientists, mathematicians and engineers all have well-developed imaging skills and find them essential for the work they do.

Both observation and imaging can be honed with practice to improve the skill of perceiving, and teachers can design opportunities for students to develop these skills. The website *Found Functions, for example,* combines photographs of curves found in nature with the graphs and functions associated with them. This site can push students to go beyond the "abstract" curves in their textbooks, and observe the "underlying mathematical reality" of objects in the world. This type of exercise utilizes knowledge highlighted in the TPACK framework where the use of technology is inextricably linked to the needs of pedagogy and content.

Patterning

Creative practitioners are always involved in recognizing and creating patterns. Recognizing patterns involves identifying a repeating form or a plan in a seemingly arbitrary arrangement of things or processes. Recognizing is the analytical part of patterning, while forming is basically a creative act of constructing new patterns. For example, when architects study a landscape and then utilize the patterns they see to design a building they are both recognizing and creating patterns. Innovative writers and poets also do this, relying on their knowledge of linguistic patterns and structures, with their own innovations, in order to dream up a new story, poem, or other form of writing (Root-Bernstein, 2003; Gardner, 1983).

Teachers can help students develop patterning skills within and across domains. One example demonstrates how the TPACK framework might be used to develop patterns in math and/or music, using freely available DJ software called trakAxPC. This software lets users download music samples and copy and paste them into a mixer. Students can cut the samples into smaller units of sound and rearrange them. What makes this compelling, from a TPACK standpoint, is that students can manipulate the software to help them describe and explain fractions, ratios and percentages. By connecting musical concepts such as rhythm and tempo to mathematical concepts (ratios and percentages, etc), students can creatively find and build patterns. The elements of TPACK in this lesson are just one example of the myriad possibilities of how technology, pedagogy and content can seamlessly combine to design learning environments that promote students' patterning skills.

Abstracting

Creative people use *Abstracting* in order to concentrate on one feature of a thing or process, in order to boil it down to basics and grasp its essence. Scientists, for example, eliminate superfluous traits from a physical situation (i.e. shape, size, color, texture, etc.) to key in on features of interest such as boiling point or mass. Another aspect of abstracting is the finding of analogies between seemingly disparate things. We may be more familiar with poets using analogical thinking but scientists do it as well. Newton's comparison of the moon to a ball thrown so hard that its descent misses the earth and passes into orbit is an analogy as well, and one that led to the theory of universal gravitation.

A creative example of abstracting is given by a professor of mathematics to her students, to write mathematical poetry and share it on the web. Writing creatively and deliberately about mathematical topics necessitates a deep understanding of both poetry and mathematics. In order for students to retell a mathematical proof or idea in a new and different way, they must fully understand the main idea (to abstract) and then "translate" this through analogies and rhetorical moves into rhyming verse. Sean Nash, a high school biology teacher at St. Joseph Missouri has extended this to the domain of science as well and has written extensively (on his blog) about its pedagogical value. His students have written dozens of poems that they share with the world on their class site. This lesson shows us how technology, pedagogy and content are bound together towards a common goal of transformative learning, and to facilitating the trans-disciplinary skills of abstracting and analogizing.

Embodied thinking

Embodied thinking involves two skills which generally feed into each other - *Kinesthetic Thinking* and *Empathizing*. Kinesthetic Thinking means thinking with the body, including the sensations of muscle, skin and sinew; and the feelings in the body of movement, balance, and tensions. For example, in his thought experiments, Einstein imagined himself as a photon, and described not only what he saw, but what he *felt in his body* (Root-Bernstein, 2003). Besides this trait of bodily thinking, an important element of embodied thinking is empathizing, or imagining oneself in another's position, or thinking and feeling as they would. Actors, poets, and novelists, for example frequently empathize with characters in order to portray them in interesting ways. Individuals in the sciences must also sometimes apply empathetic thinking to understand other organisms, even non-living things and processes.

Technology can easily engage embodied thinking to illustrate a number of concepts. For example, by using a tilted and time-infused version of the Cartesian coordinate system (a dynagraph) in a math applet created with Geometer's Sketchpad, teachers can demonstrate the properties of a mathematical function. In such an applet students drag the input point A along a horizontal axis, and the output responds by moving appropriately according to a certain rule or function. Students can *see* the function traced over time, and *feel* the tempo of it as the input is pulled along the axis. Students can watch the motions of such functions with the same curiosity they might direct toward human behavior, asking, "What will they do next? Why are they moving like that?" From a TPACK standpoint, this is a simple but powerful way to fuse technology, pedagogy and content in a kinesthetic manner. The learning experience is transformed from static to tactile.

Modeling

Modeling is to represent something in real or theoretical terms in order to study its nature, composition or purpose. Artists create and draw on models often by preparing smaller views of a piece of art in advance of creating it. Scientists also employ basic models of things and processes. Modeling requires that we employ abstractions or analogies, and more importantly that we use the facility of *dimensional thinking*, that is our thinking with respect to space and time. Creative people think dimensionally when they change the scale of things, when they take two-dimensional information on blueprints and construct them in three dimensions, or vice versa. Dimensional thinking, paired with abstractions and analogies, help create models of things or processes that explain the real world.

As a part of the *Bits to Atoms* project at the University of Virginia, teachers use cheap, portable and light-weight die-cutting machines to teach mathematics and visualization to children as young as 2nd graders. Students can develop their 3-dimensional visualization skills by designing 2-D cutouts that are then die-cut and constructed into 3-D shapes. Examples that have been used include models that depict the Earth's major tectonic plates that are designed to be cut out and assembled with the aid of a used tennis ball. These are explorations that combine the power of manipulating digital bits and bytes with the physicality of atoms.

Deep Play or Transformational Play

Playing is something that we do just "for the fun of it". When innovative people play with things or concepts or processes, they may open doors to new ways of thinking via unexpected breakthroughs. Creative people in different disciplines all play with distinctions, boundaries, unassailable truths and the limits of utility and it is through this play that they also transform. We call this deep-play to distinguish it from everyday play, which can be superficial. Deep play in contrast is creative, seeking to construct new ways of being in the world. In this, our approach is consistent with current research on educational games and learning, particularly the idea of epistemic games (Gee, 2004; Prensky, 2001; Shafer, 2005).

Mathematicians often describe their work as being akin to play. Through video games, simulations, puzzles, and interactive software students can engage and play with ideas, propose solutions and test them. In some way, many of the examples already provided above can be seen as examples of play. The *crucial difference* is that the essence of play is its open-endedness and that needs to be considered when thinking of including play in the classroom.

Synthesizing

The final cognitive tool ties together all the tools discussed above. Synthesizing entails putting multiple ways of knowing together. When we fully understand something, our feelings, senses, knowledge and experiences come together in a multi-faceted and cohesive kind of knowing. A person feels what they know and they know what they feel. For example, Einstein noted that when he sailed he felt and experienced mathematical equations occurring via the boat interacting with the wind and the water. The creative process is often described by artists, writers and scientists as coming together of the five senses and their emotions, in an aesthetic and intellectual experience which is difficult to dissect. When feeling and thinking work together, creative and intellectual processes are far more powerful and have been described as being "synesthetic."

The act of synthesizing is difficult to describe. It is similar to Dewey's idea of an educative experience, where continuity of an individual's past interacts with the present situation to open up a person's access to future growth experiences. By bringing together the previous six habits of mind, synthesis allows for the development of deeper connections between subject matters. Thus, these ways of thinking, and the examples that go with each, are not completely independent of each other. Figuring out the mathematical equations underlying shapes in nature is as much a process of perception as it is one of construction. Writing a poem is as much about pattern forming as it is about abstraction. In this these six tools work together to develop a synthesis greater than the sum of its parts.

Conclusion

These seven cognitive tools, which emerge out of disciplinary practices and are yet universal in their application, are key aspects of the kinds of transformative learning we seek to achieve.

Please note that most of the examples we've provided require educators to repurpose existing tools for pedagogical purposes. For instance using the die-cut printer for teaching solid geometry was not something the tool was designed for – but it is an extremely powerful tool for doing so. We have described this idea of "creative repurposing" in greater detail in other publications (Mishra & Koehler, 2003; Mishra & Koehler, 2005).

Also, the reader may have noted that all the examples provided are connected to mathematics. This choice should not in any way suggest that these seven cognitive tools are applicable just for this domain. Quite the contrary, as "*trans-disciplinary*" skills they can, and should, be applied across other domains. One of the reasons for choosing mathematics is that mathematics is often seen as a dry subject, restricted to formulaic (pun intended) problem solving strategies. What few students realize is that this dull conceptualization of mathematics is very different from how practicing mathematicians see it. Mathematics can be (and has been) the basis of many artistic endeavors: from the tessellations of M.C. Escher to the songs of Tom Lehrer; from the Op art of Bridget Riley to the impossible structures of Roger Penrose; from the geometric patterns of Islamic architecture to the three-dimensional geodesics of 60-atom carbon molecules. All of these go to show that mathematical sophistication and artistic representation, far from being divorced from each other, actually do go hand in hand.

To realize that many students do not get to explore this rich conceptualization of mathematical thinking is tragic, denying them access to some of mankind's greatest achievements. One could easily replace mathematics with writing, or music, or science or political science, and the argument would still hold true, though the examples would change. We believe that it is through this emphasis on trans-disciplinary cognitive tools and intelligent uses of technology that students can learn more deeply within and across domains, thereby have the potential to be transformed in how they view themselves, and their possible futures.

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