The Well-Tinkered Mind

By Cathie M. Currie, Ph.D.

You sit in a classroom: white boards, white walls, bright florescent lights, droning air handler system, listening as a teacher recites a well-prepared physics lesson from professionally designed color-filled slides. Now see yourself crowded around a table in a classroom filled with noisy, chaotic student workgroups. You and your fellow students try to build a bamboo bike, a solar energy converter, and a counterbalanced non-motorized elevator. At the end of the class sessions, the lecture students receive copies of the slides to study, and the tinkerers pile their unfinished project models into boxes. Which classroom was more successful? The professionally delivered lecture, or the unfinished tinkering projects? How much learning occurred in the sessions? Which class do you prefer?

Tinkering, a cherished hobby of yesteryear, has reemerged as a novel catalyst for student engagement and higher-level thinking in thousands of school classrooms and after-school programs across our country. Student tinkerers of past eras built crystal or vacuum tube radios and telescopes. Students now build robots from commonly-available items, calculate solar energy availability for geo-environmental conditions, and design sustainable transportation or water purification devices for developing regions.

We can intuitively perceive that tinkering stimulates active participation in learning. However, educators need to know how cognitive and educative gains are produced in tinkering experiences to allow us to maximally develop the educative experience. We also need to evaluate new teaching methods to discern their effects on civic responsibility and emotional development. Educative games present example of a novel educative experience that has been widely implemented without a full understanding of its effects. Many educators champion games as a way to get on their students' radar screen, but we do not yet understand the full effect of the games on student cognition, learning, motivation, and emotion. Some education games are valuable knowledge-changers, but a game may have negative effects that outweigh their benefits.

To ensure that we maximize benefits and minimize unintended side effects, we need to analyze new education methods using theoretical and practical perspectives. As Kurt Lewin, the founder of social psychology in America, observed "Nothing is so practical as a good theory."

As a first step, a task analysis of tinkering framed by cognitive theory reveals that the experience is comprised of a broad set of perceptual, cognitive, interpersonal, and motoric experiences. Tinkering is a semi-structured learning experience that includes visual and tactile perception, motor control and coordination, group communication and cooperation, problem-solving, curiosity and exploration, and just enough inter-student conflict to keep things edgy.

At the practical level, the success or failure of each student's effort offers feedback and validation on a large set of trial-and-error and strategic hypotheses: "I wonder what would happen if I tried to do . . . .? It seems to me that if we do X then . . ." Some of these hypotheses are discussed at the group level, and some hypotheses remain individual and tacit. Some operations and reasoning efforts are executed by individual students, some are concerted group efforts, and others are experienced through observing others' actions. The result of these individual, concerted, and observed efforts is in the various forms of feedback from the mechanical manipulations and reasoning efforts. It worked, it didn't work, it worked partway . . . maybe we need to try it this way. Most importantly, the educative feedback is not extrinsic praise or correction from an instructor. Tinkering produces a success/failure response from the real world. The tinkering feedback increases intrinsic motivation that compels further effort.

The students' iterative effort and the resulting feedback builds their representation of the mechanical nature of a real-world system and processes. We call this representational learning – learning that builds a cognitive model of the physical world and its dynamic processes, and relies on real-time spontaneous feedback to validate or correct the models in our mind.

How does representational learning differ from other types of education? Among the many theories and models of learning that are available, three learning theories offer a hierarchical description of the major results of formal education: associative learning, constructive learning, and representational learning.

Associative learning is a first-stage learning process. Associative learning is our ability to recite knowledge to which we have been exposed, and for which our production of correct response is reinforced. For example, students learn that "'i' comes before 'e' except after 'c'" in the spelling of most English words. Students who emit the correct spellings of 'receive' and 'believe' are rewarded, while those who misspell 'i and e' words are corrected. We associate reinforced responses to specific stimuli which can be words, concepts, or logical reasoning. The correct answers are proffered by the teacher, and the student recites the reinforced response. We often refer to associative learning as 'rote learning' or memorizing.

Early to mid-20th century behaviorist educators and psychologists viewed associative learning as the only acceptable instruction process. Behaviorists forbade psychology from inquiring about mental activity, viewing such events as unreliable, unmeasurable, and therefore unscientific. Behaviorists were unconcerned with creative thinking.

Many of us resist the behaviorists' reductionist stance, but we must not discount the beneficial role of associative learning. Associative learning helps us develop a base of knowledge on which we can begin to build a fuller understanding when we learn in a new area or topic. Associative learning is also an incessant and somewhat automatic process; we readily develop 'associations' between objects or events and emotional reactions such as hearing a thunder clap and fear, and then developing a fear of the dark.

Behaviorist principles explicitly dominated education and psychology in the United States from the mid-1940's through the 1980's, and continues to tacitly predominate in the lecture instruction and multiple choice testing that are the mainstays of our current education system. Many educators do not fully realize that multiple choice tests measure recognition, that a question and response were associated in a lecture or textbook, rather than usable learning. Authentic measures of learning, which require students to recall information and procedures to solve problems, are widely resisted because of our continued reliance on associative instruction and the ease of using multiple choice testing.

Constructive learning is a second major type of learning, based on Piaget and neo-Piagetian research. The constructive theorists posit that after children begin to understand language, we construct an internal understanding of our knowledge through discussions and questioning with our teachers and other learners. For many of the constructive theorists, knowledge is processed in our semantic and symbol-based semiotic systems, relying on analogies and abstractions to create and share meanings that develop our understanding of reality. Some radical constructive theorists go so far as to claim that reality exists only as it is understood within our minds; that an objective reality does not exist and that 'deconstructing' reality is the ultimate cognitive process to gain understanding and meaning. Intriguingly, Piaget did not disavow the existence of an objective reality, focusing instead on the child's ability to accommodate or assimilate to a physical reality based on feedback from very real structures. Many of the constructive theorists appear to simply neglect the necessary articulation with our physically real world, having established a comfortably elaborated knowledge system within their verbal domain. Some constructive theorists advocate discovery learning which can involve the mechanical dynamics of the real world, but often with the assumption that instructional guidance restricts learning. Proponents of tinkering, in contrast, generally design tasks that have clearly understood goals and provide guidance for their learners.

I am, of course, simplifying the constructive position and thereby misconstruing the many nuanced levels of articulation with reality among the various constructive theory versions. But the major emphasis in neo-Piagetian theory is that knowledge is built upon our shared communication within our semantic and semiotic systems. For the most part, except for those who are prescient in mathematical ability, the constructive learning operates primarily within our verbal domain. Constructed verbal thinking is organized into two networks. Our declarative network contains information about specific events and information: the facts of human knowledge. We also construct a procedural network on how to perform specific mental or physical processes using IF and THEN reasoning. The current emphasis on standardized multiple choice testing has produced an over-emphasis on declarative knowledge, to the expense of developing our students' procedural ability.

The ease and breadth of our verbal capacity becomes, in a sense, a trap that reduces our effort to incorporate the larger physical world into our reasoning processes. Our ability to communicate easily leads us to resist operating outside of our comfort zone. As a result, much of the physical world available to our sensory experience remains, as William James described it in 1890: "A booming buzzing confusion . . ."

Representational learning, in contrast, is developed from direct experiences with physical reality. The representational learner organizes the overwhelming onslaught of information available through sensory perceptions, guided by contemplative reasoning, to develop and test representational cognitive models. Representational learning is initially present as our early form of learning. Infants from birth to 18-months of age actively develop representations of objects by exploring everything in their environment; all available objects are investigated, pushed, thrown, slammed against other objects, broken, climbed on, pulled, or mouthed. Infants are little scientists, highly curious, doing hundreds of experiments on every aspect of their social and physical environment.

At about 18-months, infants begin to symbolically represent objects and concepts in language. For many children, the advent of language signals an end to their hands-on learning stage, and their representational thinking gives way to a more internally cognitive contemplative process that replaces their curiosity-driven physical exploration. At that point, parents and teachers reinforce associative and constructive learning, and their extrinsic rewards reduce the child's intrigue with developing a full representation of the real world. Children, especially those who are compliant with instruction and rewards from parents and teachers, seem to readily turn away from a continuing development of their representation of physical reality. Rochel Gelman, a prominent cognitive psychologist at Rutgers, dramatically describes how our voracious learning ability in infancy fades away in early childhood, leaving us to "get to the middle of the lake without a rowboat."

Some children, however, persist in using representational learning despite their advent of symbolization and language development, and they resist the influence of education's emphasis on the associative and constructive domains. Representational learning that persists throughout childhood and into adulthood may confer cognitive benefits. The persistently-representational thinkers, if they simultaneously develop their associative and constructive learning so that they incorporate their mechanistic and systems thinking into their semantic and semiotic thinking, appear to have more fluid, and yet more reliable, linkages between their various disparate knowledge and skill domains. Much of this coordination is thought to occur in the episodic buffer of our working memory.

Notably, the Noble physicists Albert Einstein and Richard Feynman resisted participation in speech until mid-childhood. These preeminent scientists were so compelled with representational learning that they apparently felt little need to change course into the socially interactive verbal stream of human language. When Oliver Sacks, the neurologist who authored 'The Man Who Mistook His Wife for a Hat, recently lamented in a New York Times essay that our safety-conscious science education lacks yesteryear's accidental chemistry lab explosions that had ignited his own learning storm, he was clearly describing representational learning. Much of the training of scientists and physicians has intuitively attempted to re-instill representational learning, though without a consistent theory-based understanding, and with varying degrees of success.

Tinkering experiences reawaken the vestiges of repressed representational learning, and reactivates the early nascent scientist in each of us. The tinkering student relearns how to manipulate objects in their environment to elicit feedback on the true nature of physical reality. Tinkering increases the students' solution space, and allows linkages between previously unconnected knowledge and skill domains. Tinkering ignites curiosity, and builds dynamic models. We hypothesize that tinkering, and the representational thinking it induces, aids productive and innovative problem solving ability.

Those of us who promote TRIZ can readily appreciate the value of tinkering experiences and representational thinking. However, our education system rarely uses representational learning or thinking. Academics value abstraction over physical realism, which is the essence of representational thinking. A person who uses tinkering as an occasional tool can be regarded as clever and resourceful, but those who plied the trade of tinkering were treated with distain and suspicion. The tinkers' tool for mending pots, a dam, is an example of worthlessness. We can readily anticipate that education will resist mainstreaming tinkering experiences, in the way that process is pushed to the periphery in our education system. However, it may be well worth our efforts to promote tinkering as a way to develop TRIZ-ready minds, regardless of resistance from non-TRIZ educators.

In early the 18th century, Johann Sebastian Bach began tinkering with a tuning problem that limited the range of scales for keyboard instruments. Bach created an innovative tuning system that remains in use today, and demonstrated its success by composing preludes and etudes for each of his retuned scales. His collection of scale exercises was published as The Well-Tempered Clavier, one of the major and most beloved creations in the history of western classical music. Long live tinkering!

About Dr. Currie,

Cathie M. Currie, Ph.D. is a cognitive social psychologist who specializes in medical and science education. She heavily engaged with problem solving and innovation thinking skills, authentic assessment, and minority access to higher education. She teaches psychology at Adelphi University in New York, and conducts research in medical, health professions and science education. Dr. Currie develops innovative curricula materials to help students learn how to think, not what to think. She is an adviser for the Altshuller Institute for TRIZ Studies, Worcester, MA. in their efforts to enhance problem solving and innovation instruction for science, technology, engineering and mathematics education and to expand the STEM workforce in the United States. Before Dr. Currie did her Ph.D. at Columbia University's Graduate School of Arts and Sciences, she developed the Women's National Soccer Team for the United States Soccer Federation, coached soccer, and promoted the beautiful game as a sports writer.