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## Commentary

# Tools for Innovative Thinking in Epidemiology

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Innovation is the engine of scientific progress. Concern has been raised by the National Academies of Science about how well America is sustaining its "creative ecosystem." In this commentary, the author argues that we can all improve our ability to think innovatively through instruction and practice. The author presents a series of tools that are currently being taught in a curriculum developed at the University of Texas, based on earlier evidence-based creativity training programs. The tools are these: 1) finding the right question; 2) enhancing observation; 3) using analogies; 4) juggling induction and deduction; 5) changing your point of view; 6) broadening the perspective; 7) dissecting the problem; 8) leveraging serendipity and reversal; 9) reorganization and combination of ideas; 10) getting the most out of groups; and 11) breaking out of habitual expectations and frames. Each tool is explained using examples from science and public health. It is likely that each of us will identify with and agree with the usefulness of one or two of the tools described. Broader mastery of many of these tools, particularly when used in combination, has provided our students with a powerful device for enhancing innovation.

creativity; epidemiology; innovation

Abbreviations: HPV, human papillomavirus; IQ, intelligence quotient.

Every generation needs innovators. Innovation is synonymous with human progress and is critical for addressing the greatest threats to humanity—hunger, cancer, Alzheimer's disease, obesity, and emerging infectious diseases, to name a few. Like any highly valued commodity, we crave innovation and we fear its loss. Our fear may be well founded. A blue-ribbon committee of the National Academies of Science, in a report entitled *Rising Above the Gathering Storm Revisited: Rapidly Approaching Category 5* (1), recently warned that modern American science is not sustaining its "creative ecosystem." American scientific output (measured by the number of peer-reviewed publications) was surpassed by the European Union in 1995 and by Asian-Pacific countries in 2008 (2, 3). Solutions proposed in the report included more funding for America's scientific universities and more rigor in secondary school science education.

Are more funding and a better pipeline the solutions to enrich scientific innovation? How do we maximize our own creative potential? If we believe that creativity is innate, then we should simply keep doing what we have been doing. However, 30 years of research have demonstrated that creativity can be taught (4, 5). Thus, another solution to the "creativity gap" is for all of us to educate ourselves and our students to be more innovative. Creativity training programs have been evaluated in several large meta-analyses (4, 5). The success of such programs has been substantial and consistent. In one analysis of 70 creativity training programs, participants increased the number and originality of the ideas they generated 2- to 3-fold (5). Well-designed programs containing discrete tools and consistent practice have been validated within K-12 instruction, higher education, and business. In business settings, training has led professionals to demonstrate a greater preference for novel problem-solving and more flexibility in work performance (6, 7).

Here I outline components of an effective creativity training program for epidemiology. It is presented in the form of an innovation toolbox.

## Tool 1: Finding the right question

Generating an innovative answer requires asking the right question. As innovators, we must be curious and so must ask reams and reams of questions. Posing random questions, however, is like throwing darts blindfolded. Somehow we must find our way to asking the right question in the right way. How do we do it?

Important questions that lend themselves to creativity reside at an optimal intersection of place and time. The right time/right place requires a convergence of technology, theory, and evidence. Without the correct technology, we innovators cannot "see" what is there. Without the appropriate science, we do not have a basis for developing the device that allows visualization. For example, cervical cancer was recognized as early as the 19th century to have the characteristics of a sexually transmitted infection, including its rarity among nuns, its higher prevalence in female sex workers, and its frequency among the second wives of men whose first wife had died of cervical cancer (8). However, to identify human papillomavirus (HPV) as the causal agent of cervical cancer, polymerase chain reaction had to be invented and HPV DNA had to be identified. The detection of HPV in cervical cancer lesions by Gissmann and Zur Hausen (9) in the 1970s was the ignition that established HPV as a carcinogen. Science created technology and technology created science. Innovation was at the intersection of the two.

Yet picking the right question is not simple destiny. As Pasteur noted, "Chance favors the prepared mind." Innovators know the questions "ripe for the asking" and compete fiercely to be the one to first publish the answer. In a remarkable number of cases, scientific greats beat out their competitors by days or weeks. Alexander Graham Bell submitted his patent for the telephone only hours before his competitor Elisha Gray did; thus, the nation's first telephone company did not become "Gray Telephone." Darwin published *On the Origin of Species* only after the work had sat in his drawer for 2 decades, because he was on the verge of being scooped by the enthusiastic naturalist Alfred Russell Wallace (10).

Innovators also have a gift for phrasing questions in a way that goes precisely to the heart of the problem. Moreover, great discoveries come from asking questions that are big. Thus, asking "What about social class alters cardiovascular risk?" as Jeremy Morris, the father of physical activity epidemiology, did or "How does a poor country gain agricultural self-sufficiency?" as Norman Borlaug, the father of the Green Revolution, did involved big questions that led to big answers.

## Tool 2: Observation

We innovators must be acute and perceptive observers. There are at least 2 barriers to observation that must be overcome. The first is habituation. Habituation is the physiologic process of ceasing to take notice. In experiments conducted in the microscopic roundworm, *Caenorhabditis elegans* (which has only 302 neurons), repeated sensory stimulation resulted in the firing of fewer and fewer neurons (11). Humans are the same way. To overcome habituation, we must ceaselessly and tenaciously attend to details.

The second barrier to observation is that we often see only what we expect. Overwhelmed with too much sensory information to process it all, we selectively attend through the filter of our assumptions. Innovators tend to be particularly good at being aware. Robin Warren, a clinical pathologist working in a community hospital in Perth, Australia, won the 2005 Nobel Prize in Physiology, along with his colleague Barry Marshall, for a keen observation. Using a standard silver stain, he noticed that within the gastric crypts of biopsies from patients with peptic ulcer disease consistently resided a small, curved anomaly (12). Ultimately, he came to believe that these were bacteria, and they were remarkably common, residing in the biopsies of half of all patients. Other pathologists could have readily visualized the bacteria at the time (and in retrospect, a German team had noted the finding but had not pursued it), but all the textbooks said that the stomach, because of its acidic environment, was sterile. Stress and acid were considered to be the causes of gastritis. No one expected or believed that the stomach could contain bacteria.

Barry Marshall, a recently trained medical registrar, joined Warren's research in 1981 and was able to culture the bacterium from ulcer tissue and to demonstrate that it was *Helicobacter pylori*. What Warren and Marshall lacked was any demonstration that *H. pylori* caused peptic ulcers. After several years of trying without success to infect pigs, Marshall ultimately drank a Petri dish full of the bacteria. He developed symptoms of gastritis. Assuming that the scientific community would not consider his own self-report, Marshall allowed himself to be subjected to endoscopy in order to prove that he had developed classic peptic ulcer disease.

Today it is known that 80%–90% of peptic ulcers are caused by *H. pylori*, and antibiotics are a backbone of treatment. Anyone could have seen it—but only Warren and Marshall were willing to trust their eyes rather than their expectations.

## Tool 3: Analogy

Analogy is one of the most commonly used methods to promote innovation. Lessons learned from one situation are applied to another. Blood vessels thus become like road systems or waterways. Light behaves like a wave on a pond.

The human mind readily constructs associations. The wider our spheres of association, the more likely 2 webs of associations are to overlap into an analogy. Paul Baran, in developing the concept called "packet switching," which underlies the Internet, related the web of computers he envisioned to neuronal pathways in the brain. He imagined messages traveling through the system like letters placed in a postbox (13).

Edward Jenner fashioned the first vaccine by injecting cowpox under the skin of a few selected research subjects. The analogy between smallpox and cowpox was based on the keen observation that milkmaids did not become ill during smallpox epidemics. Current notions such as the imposition of a soda tax to prevent obesity are based on the success of cigarette taxes in reducing cigarette smoking.

## Tool 4: Juggling opposites: deduction and induction

Observations are critical to devising theories. Inductive reasoning is the process of generalizing based on individual instances. In genetics, for example, Gregor Mendel observed thousands of crosses between pea plants, and from this he built the theory of classical inheritance. Deductive reasoning starts from assumptions that are stated as axioms or givens, and these are used to reach a logic-based conclusion. Theoretical mathematics is a purely deductive science.

Whereas induction moves from observation to theory and deduction moves from theory to observation, innovation often combines the two. Darwin, for example, used deduction to extend observation. He elaborated on what could be directly observed, such as the beak pattern of Galapagos finches (8). Using a leap of logic, he deduced that the variation in beak sizes had arisen by means of the best-adapted beaks' outcompeting others for a given environmental niche. The diversity of ecosystems in the Galapagos Islands had produced a range of beak sizes.

The theory that pelvic inflammation increases the risk of ovarian cancer came from a combination of induction and deduction (14). The empirical evidence was that risk factors such as talc use (talc having a fibrous structure much like asbestos) and pelvic inflammatory disease cause inflammation and have been shown to raise ovarian cancer risk. Protective factors such as ovulation and tubal ligation reduce the risk of inflammation and lower ovarian cancer risk. Putting these patterns together led to a logic-based theory. Induction necessitates keen observation. Deduction is the permission to use logic and imagination.

## Tool 5: Changing your point of view

“Don’t judge a man until you have walked a mile in his shoes” is a powerful reminder of how differently each of us sees based on our perspective. Einstein imagined traveling at the speed of light to devise his special theory of relativity. Darwin imagined himself as a plant to inform his theory of natural selection. Montessori, the educator-scientist, imagined herself as a child. Epidemiologists in global health might imagine the day-to-day experiences of impoverished residents of underdeveloped countries. This, in turn, often modifies approaches to intervention.

## Tool 6: Broadening the perspective

We innovators benefit from broadening our perspective. Take a question like, “How can we provide more nutritious foods in America’s lunchrooms?” An obvious answer might be to provide wholesome foods wrapped up as things kids like to eat (think zucchini fries). But what if we broaden the perspective and instead ask, “How do we get America to eat better?”; then the trickle of associations becomes a raging river. Indeed, the question generates not only ideas but more questions. These might include: “What is the role of price; what about culture; how about convenience?” Just paddling down the economic branch, one may ask, “Why do low-income families buy less nutritious foods?” “Why are foods of high nutritional value often more expensive?” “What effect do agricultural subsidies have on food pricing?” Broadening the perspective greatly expands the range of novelty.

Ancel Keys, the famed cardiovascular epidemiologist who developed the Mediterranean diet, expanded his research network internationally to understand links between diet and heart disease. Among disparate populations of 40- to 59-year-old men in the United States, Finland, Greece, Italy, Japan, the Netherlands, and Yugoslavia, Keys and his international colleagues enrolled 12,770 men, mostly from rural communities and consuming traditional diets, into the Seven Countries Study (15). In explaining the spectacular differences in rates of cardiovascular disease between middle-aged men in Japan and the Greek islands versus the United States and Finland, Keys inferred that diets low in saturated fats (less than 10% of calories) accounted for lower heart disease risk. Not only did this explain the low rates in Japanese men, who consumed mainly rice, fish, and vegetables, it also explained the low rates in Greece, wherein the diet derived 35% of its calories from fats. Greek fats, it turned out, were the unsaturated kind found in fruits/vegetables such as nuts and olive oil rather than the saturated kind found in animal products, such as the meats, cheese, and butter consumed by the Finns. By expanding the question into the international realm, Keys was able to discern the effect of high-fat diets and, more specifically, the effect of saturated fats in the diet.

## Tool 7: Dissecting the problem

Often problems are inherently so complex that they cannot be validly examined as a whole. In 1950, with 40 million cars on the road, over 33,000 people died in traffic accidents. Sixty years later, while the number of cars had exploded to 248 million, the number of highway fatalities had fallen below the 1950 crude number of deaths (16). Age-adjusted death rates from motor vehicle accidents per 100,000 population in the United States fell from 22 in 1976 (the earliest calculation seemingly available) to 14 in 2007. Improved highway safety has resulted from dissecting the problem.

Greater automobile and highway safety has been achieved by appreciating the many factors contributing to driving fatalities. Just the basic physics of a 2-car crash tell us that the force of an impact depends on each car’s speed and change in velocity. Within change in velocity, important features are each vehicle’s mass and the distances between centers of gravity. After testing various ways to improve each of these components, automotive engineers successfully employed more durable materials, considered appropriate centers of gravidity, and designed safer bumpers. Highway engineers recommended appropriate speed limits. These and other solutions to the dissected problem of driving safety, such as seat belts, are interventions we can all thank for our lives.

Dissecting the problem leads to convergence. J. P. Guildford, generally considered the founder of the field of psychometric measurement of creativity, defined divergent thinking as the spawning of a wide array of ideas in response to a problem (17). Convergent thinking, in contrast, is the determination of a single best answer: the solution to a multivariable equation, for example. Although generating many novel ideas drives novelty, the testing of very specific ideas and components of ideas allows us to converge on a single best solution so as to assure scientific progress.

## Tool 8: Reversal

Reversal works either by flipping assumptions or by realizing the import of a serendipitous twist. Serendipity—appreciating a “happy accident”—is a particularly potent trigger for innovation. Not everyone grasps the implications of finding the reverse of what was expected, but innovators do.

Alexander Fleming, the father of antibiotics, is the poster child for serendipity. Upon returning to his laboratory from a vacation in 1928, he noticed mold growing in one of his Petri dishes (18). Unfortunately, it had ruined his experiment by killing the *Staphylococcus* bacteria he was studying. In retrospect, others had experienced the same problem and had simply discarded their bacterial plates as failures. But Fleming recognized the mold not as a calamity but as an opportunity. His subsequent work focused on how the mold inhibited the growth of bacteria. Ultimately, he identified the mold as *Penicillium* and called the juice derived from the mold penicillin.

An equally potent strategy is to purposefully create a reversal. Joseph Goldberger, a public health officer, discovered that pellagra was caused by a nutritional deficiency (niacin) (19). When he was dispatched in 1914 to investigate asylum-based outbreaks of this devastating condition, he believed, as did all scientists, that pellagra must be infectious. Goldberger came to question that assumption when he noticed that the spread of pellagra did not follow normal patterns of contagion. Only patients, never staff, were affected. Ultimately Goldberger had the radical insight that the disease was not due to the *presence* of an infectious agent but to the *absence* of some nutrient. When he fed patients fresh milk, meat, and vegetables, he cured their pellagra and prevented new outbreaks.

### Tool 9: Reorganization, combination, and rearrangement

"Rearranging the deck chairs on the *Titanic*" is a flippant aphorism for doing something useless, but reorganizing, combining, or finding unusual uses for previous ideas is far from useless. Humans have a tendency toward what gestalt psychologist Karl Duncker called "functional fixedness." Once we are taught a use for a particular object, we are fixated on that particular usage/function. A classic experiment demonstrates the concept of functional fixedness. Given a candle, a book of matches, and a box of thumbtacks, subjects are hard-pressed to attach the candle to a wall. Most people try to affix the candle to the wall with a thumbtack or melt it onto the wall (neither of which works). The trick is to take the thumbtacks out of the box, put the candle in the box, and attach the box to the wall with a thumbtack. The need to alter the function of the box so it becomes a candle base stumps most subjects. Innovators can rearrange and recombine parts from other ideas, inventions, or disciplines to gain originality.

Combining disciplines can create unusual insights. When urban planners, geographic information experts, and nutritionists intersected, their work cataloging food availability led to the realization that lack of access to healthy foods is a likely contributor to obesity in poor city neighborhoods. Nanoparticle engineers working with pharmacologists are designing novel systems for drug delivery. Molecular biologists and computer informatics experts are creating virtual biologic systems to explore their complexity. This kind of cross-disciplinary work has become so common and so fruitful that it has created a score of new fields: bioengineering, genetic epidemiology, astrophysics, neuropsychopharmacology, and many more.

### Tool 10: The power of groups

Even when epidemiologists appear to be lone wolves, we work within a network of colleagues, mentors, and role models. Discovery builds on what has gone before, and discoverers train the scientists of the future.

The discovery of the structure of DNA, often credited solely to Watson and Crick, was actually group science. The two could never have worked it out had they not seen X-ray crystallography photographs taken by their colleague Rosalind Franklin. In a conference that Watson and Crick convened only months before they "broke the code," scientists gathered to share data and insights. Franklin's sharing of her peek at DNA's hazy helical outline gave Watson and Crick (and Franklin—she published the structure concurrently with their *Nature* article) the clues needed to decipher the historic structure.

In the 21st century, the power of social networks, self-organizing collectives, and open-source journals has brought communal scholarship and creativity to a pinnacle. The online encyclopedia Wikipedia, aided by thousands of volunteer contributors and hundreds of volunteer editors, has become a preeminent source of information for the world. YouTube has become the arbiter for creative talent. Linux is a creative operating system fashioned by $1 billion in free man-hours of work (13). Perhaps the greatest societal transformation to come out of science in our lifetime has been the Internet's creation not only of a new communications technology but of a new and powerful form of collective productivity.

### Tool 11: Frame-shifting

Normal thinking is constrained by habitual patterns which linguists call "frames." Frames are a structure of expectations that we use to interpret new information. They allow us to think and speak in a common and highly efficient shorthand. Using them, we construct norms. If, sitting in a lecture hall, a person were to sneeze and then grab her neighbor's sleeve and wipe her nose on it, would the neighbor be shocked? Of course he would. What just occurred was a frame break. Such a thing is unexpected. Frames—agreed-upon assumptions—provide predictability.

Without frames, we would constantly have to check our suppositions before every thought or action. Working within a frame-free scientific world would mean having to start every experiment from first principles. For all practical purposes, it would be paralyzing.

Nonetheless, frames are fundamentally constraining. In a recent experiment, subjects were asked to devise solutions to rising crime levels in a community, after reading a brief description (20). When the narrative characterized crime as a contagion, respondents proposed social solutions such as reducing poverty and increasing education. When crime was described metaphorically as a beast, subjects selected punitive legal interventions. Many other experiments have shown that our beliefs, attitudes, and actions are guided by the way situations are framed.

Normal scientific practice is deeply embedded in assumptions and expectations. Scientific leaps, in contrast, require upsetting existing theories or breaking frames. Albert Einstein understood this intrinsically when he said, ‘‘No problem can be solved from the same level of consciousness that created it.’’

Consider what it would have been like to be a scientist working before Robert Koch and Louis Pasteur formalized the germ theory in the 1860s and 1870s. Microscopy had been available since 1670, when Anton Van Leeuwenhoek visualized cells within plants and animals. After the discovery by Siebold in 1865 that bacteria are unicellular, scientists were regularly recognizing microbes within diseased human tissues (21). But what did the presence of such bacteria mean? Today, of course, we would immediately know that the microorganisms in those tissues were pathogenic agents, yet pre-germ-theory scientists had no context for such an interpretation. Instead, they were steeped in the idea that bacteria spontaneously generate. If bacteria simply mysteriously arose in fetid meat, wouldn’t the same agents similarly arise in human organs? Only after Pasteur and Koch established that specific diseases are caused by specific bacteria did scientists and clinicians have a context for understanding the genesis and spread of infectious diseases. Before that revolutionary innovation, disease seemed to appear out of nowhere and thus could never be prevented. Afterwards, Lister spearheaded antisepsis.

Breaking frames can lead to fundamental reconsideration of our belief systems about nature. In a single insight, if validated by evidence, a shift in frame can create a major innovation. A fundamental assumption about lead toxicity prior to the 1950s was that, like overdosing on alcohol or aspirin, lead poisoning was avoidable through appropriate personal precautions (22). The approach to avoiding adverse outcomes was thus individual and clinical. Herbert Needleman, while a pediatric resident during that era, saved the life of a child admitted to the hospital in a lead-related coma. Needleman describes the following scene: ‘‘I told the mother that her daughter would be all right but that she could not return home. Her house was dangerous, and a second exposure would leave her brain damaged. The mother looked at me in anger and asked, ‘Where can I live? Any house I can afford is just as bad as this one’ ’’ (22, p. 235). Needleman then says, of himself, ‘‘I suddenly understood that it was not enough to make a diagnosis and give a drug: The disease was a product of the living situation of poor people in the city.’’ A series of ingenious studies followed, showing just how common were the effects of lead among the poor of Boston, Massachusetts. Since lead concentrates in bone and bone is found in teeth, Needleman collected over 2,000 shed teeth from inner-city and suburban children. City children had a 5-fold higher level of lead in their teeth than did their more affluent brethren. Children with higher lead levels, he then showed, had subtly lower intelligence quotient (IQ) scores. Even worse, mothers with high blood lead levels bathed their fetuses in the toxin during pregnancy, and those children were fated to have lower IQs through the age of 10 years. In fact, two-thirds of poor children in Boston had evidence of clinically unrecognized toxicity from lead.

Needleman recognized lead as a ubiquitous toxin that could not, in fact, be avoided by Boston’s impoverished inner-city residents. His work changed the lead paradigm from that of treating individual cases to that of preventing population exposure.

## The toolbox as a whole

The use of one of the tools presented here may prove useful. The use of many, particularly when they are applied masterfully and in combination, seems to be a powerful device for enhancing innovation. Moreover, these tools, although adapted here for science, are the backbone of proven creativity training programs. The evidence that such programs are effective is something I can personally validate from my own experience over the past 2 years teaching the use of innovation tools at the University of Texas School of Public Health. Although our numbers are not yet large enough to provide stable estimates, we have seen students substantially improve their scores on standardized creativity tests, and we have noted qualitatively that their dissertation projects are more likely to focus on subjects that are ‘‘outside of the box.’’ In a recently published book (23), I describe the method for improving innovative thinking in greater detail.

The fact is that innovative thinking can be taught, and we now have a method for doing so. Given the import of innovation in epidemiology, our goal should be to incorporate innovation training within every epidemiology curriculum in the nation.

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