Chaos and Creativity: Liberal Education for the 21st Century

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I am a chemist as well as a college president, and in thinking about the goals of higher education I often return to two general methods that intertwine through the study of chemistry: analysis and synthesis. In analysis, chemists may take a complex mixture and break it down into separate substances through chromatography, or take a single substance and use spectroscopy to find its atomic structure. In synthesis, chemists work in the opposite direction, taking a series of simple materials (ideally, off the shelf) and combine them to make a more complex compound with particular chemical properties. Chemists go back and forth between these two approaches in their everyday work. For example, a chemist might take a natural product with certain desirable medicinal properties, purify it, and analyze it to determine its structure; then she might develop a synthesis to prepare the product from commonly available starting materials.

I begin an essay on the future of liberal education with the concepts of analysis and synthesis because I believe the processes inherent in each—breaking down and putting together—characterize many of the activities central to our college curricula. Let me explain.

A great deal of learning involves analysis, taking something complex and breaking it into simpler pieces that we already understand, or that we can focus on sequentially. In an English class we may do a close reading of a poem, looking at it line by line to see the use of language, meter, or metaphor. In a sociology class we may attempt to separate out the effects of five different factors on the school systems in a city, breaking down a large problem into individual pieces. Much good classroom teaching consists of moving step by step through a complicated subject, with students realizing at the end that what seemed too hard to learn was just a series of manageable steps.

Analysis is a skill for which we prepare our students well from the very beginning. The techniques needed to succeed at SATs and other multiple choice tests often involve looking at the options, eliminating them one by one, and determining (in some cases guessing) the answer among those that remain. Students sometimes tell me that they solve a "word problem" at the end of the chapter by analyzing it to see which "worked" example in the text it most resembles, and then solving it step by step in a parallel fashion. Critical reasoning, a key outcome of a liberal education, involves developing the skills needed to analyze new problems based on experience with solutions to existing problems.

Our entire educational system is built around this process of analysis into smaller and smaller subdivisions. As students progress through college, they typically move from broad general education toward more and more focused specialized courses. This affects the organization of academic training and institutions as well: the broad contours of knowledge become increasingly divided with time into smaller and smaller fields, where only those who have completed years of study can reach the forefront. Of course, this has its value: difficult problems require detailed analysis and dedication to be resolved.

I would argue that the second concept, synthesis, is less actively encouraged and rewarded in our modern educational system. There are reasons for this. First, it is harder to test. How does a faculty member assign objective grades to the big idea that brings together several different pieces into a single whole? Second, synthesis raises questions of superficiality; while these are not always justified, it is possible to spend one's time moving from one area or field to another, searching for connections, without delving deeply into any one of them. And finally, big questions and ideas do not fit easily into the boxes that we have created for discrete areas of knowledge. Thus, for example, professors of anthropology, of sociology, and of political science, attend separate disciplinary meetings, and do not always or easily talk to one another. These disciplinary boundaries tend to be reinforced through teaching and research.

Yet the important problems we face today—from poverty to climate change to religious tolerance—are so complex and far reaching that solving them requires contributions from many fields. Synthesis is not simply desirable in this situation; it is essential. Many breakthroughs in research, whether in the sciences or the humanities, involve bringing ideas from one area to bear in another, apparently unrelated, area and reaching a true synthesis. Yet while interdisciplinary work is thus critical for synthesis, it challenges our institutional and educational systems of organization. In a 2012 conference on the future of the liberal arts college at Lafayette College, I outlined some of the structural and cultural impediments to interdisciplinary teaching and programs, but argued that, in order to foster this type of synthetic thinking, liberal arts colleges should be centers of interdisciplinary innovation.[1]

How can we help to integrate synthesis more fully into our educational systems? Many ideas have been discussed: courses on a single and complex topic team-taught by two or more instructors from different points of view; project-based courses in which teams of students bring different expertise to bear on a single problem; capstone courses in which students use their full four-year education to advance a problem faced by society. We don't need to reinvent the models that exist already, but we do need to reinvent our colleges and universities so that they support these and other approaches to synthesis in teaching and learning.

The contrast I am exploring between analysis and synthesis can be translated into the language of left-brain and right-brain approaches to seeing the world. It is now well known that the two hemispheres of the brain have largely different functions: the left hemisphere controls words, numbers, logic, and analysis, while the right hemisphere interprets size, shape, spatial relationships, and rhythm. As Daniel Pink writes in A Whole New Mind, "the left hemisphere analyzes the details; the right hemisphere synthesizes the big picture."[2] Significantly, the subtitle of his book is "Why Right-Brainers Will Rule the Future."

It is often said that the second half of the twentieth century was an era dominated by left-brain thinking. The skills to build bridges or design computers, to get to the moon or design new financial instruments, all make use of linear thinking and logic. Engineering, law, and finance all are "classic" left-brain activities, and while all of these fields remain important today, some feel that they will need to transform, especially as computers take over more and more of the analysis that has traditionally characterized left-brain thinking. In contrast, pundits argue that in the future right-brain thinking—nonlinear, intuitive, visual—will dominate. Pink argues convincingly that in an era when production becomes cheap, design dominates and helps to determine the winners. Apple has surpassed Microsoft in market capitalization in part because design is at the heart of its work.

This left-brain/right-brain dichotomy has led to considerable discussion about gender roles in the work force. The engineering and finance professions, dependent on analysis, have traditionally been male dominated, while those professions stereotypically right-brain in character-the arts, writing, design-have been more open to women. In the past, the latter professions (and, we might add, academic departments), carried lower status. Now, however, many would argue that they represent the best chance of competing in the future, when analysis can be programmed or outsourced. This has in turn led some to predict a reversal of male and female social roles and even some handwringing about the future of the male sex. Hanna Rosin, in an Atlantic article entitled "The End of Men," asks "What if the modern, postindustrial economy is simply more congenial to women than men?" She posits that "the attributes that are most favorable today—social intelligence, open communication, the ability to sit still and focus—are, at a minimum, not predominantly male."[3]

While it is important to understand the distinct areas of the brain and the effect of right-brain and left-brain activities on education and society, ultimately the people who will be successful are those who can integrate both hemispheres, relying on creativity and intuition as well as discipline and focus. Consider the approach a pianist takes to learning a difficult piece; the inspirational insight into the music requires the synthetic activity of the right brain, but hard, disciplined work, applied in a linear fashion to one section of music at a time, underlies the successful performance. While some would assign "creativity" to the right brain, I would argue that successful creative people integrate both hemispheres of their brains effectively; intuition works together with logical methods to achieve significant results. Unlike Daniel Pink, I do not think that right-brainers will rule the future; rather, individuals with fully integrated brains, or teams of individuals with different strengths who can, together, blend analysis and synthesis, will be the best positioned to succeed.

A striking observation from modern neuroscience is that the brains of 18 to 22 year olds (the typical age range for college students) are highly plastic. Of course, throughout childhood connections between synapses are made and the brain develops in response to its environment. But it is now clear that changes continue to occur through the college years and beyond (there is still hope for all of us!). Synapses can change from firing in bursts to firing more regularly, and existing pathways of connection in the brain can be further developed or can waste away. “If a neuron is stimulated to fire frequently, its synapses may grow stronger.”[4] Rats raised in environments with extensive and varied sensory input are found to have more highly branched networks of brain neurons. In short, our brains are constantly developing as we employ them in different ways.

How then can a college education be designed to foster the development of the most integrated, and therefore the most effective, brains possible? Neuroscientist James Zull addresses this question in his provocative book The Art of Changing the Brain: Enriching the Practice of Teaching by Exploring the Biology of Learning. Zull uses recent discoveries in brain science to explore how the brain responds to external stimuli, and provides a number of practical techniques teachers (especially at the college level) can use in order to “shape” the brains of their students most effectively for success in life.

People can be “trained” to do anything well, just as animals learn amazing tricks when they are rewarded. Many educators worry that the United States is headed in the direction of training rather than education, new ideas, and critical thinking. For the last ten years, our K-12 educational system has been dominated by a testing culture under the superficially attractive rubric of “No Child Left Behind.” Assessment of learning is valuable: finding out what works and what does not, and modifying what we teach and how we teach it accordingly. But what has happened since 2002 is much more disturbing. Rather than set ambitious goals for all our students, schools assess performance through a series of narrow multiple-choice tests, and more and more classroom time is devoted to succeeding on such tests, rather than on learning new ideas and thinking critically.

Recently, high school teacher Kenneth Bernstein attracted attention in an open letter[5] warning college professors that the students headed their way have now completed their full pre-college education in this test-dominated culture, and are “better at ‘filling in bubbles’ than thinking outside a discrete set of multiple choices.”[6] In his view, meaningful content and development of critical thinking and writing skills have been sacrificed for test preparation. And of course, the testing culture is heading to colleges and universities as well, with warnings from the Department of Education that we need to demonstrate value for the tuition or cost in all of our courses of study. A number of states have raised the possibility of analyzing outcomes for their universities by examining the starting salaries of graduates from different majors and closing (or charging more for) those majors that “underperform.”

This direction in higher education results in part from concern that students emerging from our colleges and universities are less competitive internationally, especially in STEM (science, technology, engineering, and mathematics) fields where the number of U.S. graduates is dwarfed by the numbers coming out of universities in China, India, and elsewhere. It is important to respond to international pressures, of course. But the solution is not to replace our successful higher education system with one in which larger numbers of students are “processed” through a less demanding program in order to increase numbers of graduates and shorten time to degree. Quality matters, even though it is harder to test.

Ironically, as the United States looks toward the success of other nations, they are looking toward us for new models of education. Leaders in other countries are recognizing that their universities are not suited to encourage the types of creativity fostered by American liberal education. Singapore has launched a liberal arts college in a collaboration between the National University and Yale University; educational leaders from Thailand have talked with Pomona College and others about how to bring liberal education to their university system; Hong Kong is moving from a British-style three-year degree to an American-style four year program, that will include broader general education coverage. Why should we be backing away from core goals for higher education at the same time that the rest of the world is discovering their value?

The jobs of the 21st Century are not ones that students can prepare for through narrow professional training. Certainly there is a place for certificate programs that directly prepare students for particular job requirements. But some of these narrowly defined jobs may disappear or be radically changed in a short time; the individuals who will thrive in such a rapidly evolving and competitive economy are those who can move from one job to another with the core skills to learn new things and respond creatively. This is just what a liberal arts education teaches.

In the 2013 State of the Union address in which President Barack Obama called on higher education to train students for immediately open jobs and asked colleges to demonstrate the value of their degrees, he also called for a new decade-long study of the human brain. Just as the human genome project mapped our DNA and connected the results to real-world medical outcomes, a better understanding of how the brain works would lead not only to breakthroughs in treating diseases of the brain but also to more sophisticated approaches to teaching and learning. One challenge I would pose is: what type of education shapes the brain into the most capable and creative organ possible? So far the evidence, exemplified by Zull's work, is that a broad liberal education, developing all the capacities, connections, and creative abilities of the brain, is the best way to prepare our students for lifetimes of constructive contribution to society.

Two recent studies have taken quite literally the challenge to connect brain science with liberal education. A Stanford study appeared under the heading "This is Your Brain on Jane Austen;"[7] in the study researchers took functional magnetic resonance imaging (MRI) brain scans while the subjects were engaged in reading excerpts from Austen's Mansfield Park. The functional MRI monitors blood flow to different parts of the brain, and thus measures which parts of the brain are engaged during a particular activity. One finding was that many more areas of the brain were engaged than expected, and that these areas differed between close reading of the novel and pleasure reading. The investigator suggested that "each style of reading may create distinct patterns in the brain," depending on the type of focus, and that attention to literary form is "a kind of cognitive training." A second study from Emory University, also using functional magnetic resonance imaging, found that when a subject read a metaphor connected to touch (such as "the singer had a velvet voice") regions in the sensory cortex that typically are excited through actual touch became active, in addition to the expected activity connected to ordinary language processing.[8]

In the same way that the Stanford study examines the activities in the brain as we engage fully with a literary text, other research focuses on visual or musical experience and the brain. For example, in the fall of 2012 I joined a group of Pomona College students on a field trip to the Getty Museum in Los Angeles to hear a talk by Nobel Prizewinning neuroscientist Eric Kandel as part of an exhibition of drawings by Viennese artist Gustav Klimt. How is neuroscience connected to art of the early twentieth century? In many rich and surprising ways, as Kandel has discussed more fully in his outstanding book, The Age of Insight: The Quest to Understand the Unconscious in Art, Mind, and Brain, from Vienna 1900 to the Present.[9]

Kandel examines the remarkable confluence of culture and science in fin-de-siècle Vienna, exemplified in artists such as Klimt and Kokoschka, scientists such as Boltzmann, writers such as Schnitzler and Werfel, and the brilliant psychoanalyst Sigmund Freud. He shows how these disparate individuals, many of whom saw each other regularly in salons and coffeehouses, are linked by a common theme of understanding the unconscious and its effect on our actions and perceptions. Kandel then turns to modern questions of neuroscience, psychology, and aesthetics, focusing on how the brain works and how we perceive art, and draws profound conclusions about creativity and the deep connections between art, the humanities, and science.

Kandel's book is no mere abstract treatise on the perception of art. Rather, he makes use of the most advanced results from experimental brain science (as well as earlier studies on subjects with particular forms of brain damage) to explore the effect of art on the brain. He starts with the retinal rods and cones and how they respond to images, and then traces the response of neurons in the visual cortex. Among other observations, he comments on the discovery by David Hubel and Torsten Wiesel that "neurons in the primary visual cortex respond not simply to lines, but to lines with a specific orientation – vertical, horizontal, or oblique. . . . Different neurons will fire in response to the different angles."[10] He concludes that that the eye "does not record the image of a scene or a person pixel by pixel. . . . The visual system can pick and choose and discard information, which neither a camera nor a computer can."[11] Kandel then describes the top-down processing of information by other parts of the brain, the higher cognitive centers. Here, stored memories are used to "compare incoming visual information with prior experiences."[12]

After this fascinating exploration of the neuroscience of perception, image, and art, Kandel discusses the relationship between creativity and the science of the brain. He describes studies that show activity in a particular part of the right hemisphere immediately before a creative insight—the "Aha!" moment. Citing none other than Mozart and Schopenhauer, he points out that such creative moments often occur when the mind is distracted by other tasks, relaxing, or dreaming. Scientists have also noted that their unconscious minds work through problems and achieve breakthroughs that their conscious minds cannot.

Kandel's work, like the Stanford experiment, illustrates the growing body of research that, I believe, underscores the profound value of a liberal education. If we narrowly train our minds – and our brains – on repetitive, linear, and logical problems (the ones that are easiest to teach and to test), we develop certain neural connections more strongly than others. But creativity – and the Aha! insights that can lead to real breakthroughs – rely on the integrative and synthesizing parts of the brain. Rote learning will do nothing to develop these capacities. The value of a liberal education is that it can help a linear thinker to develop the ability to make leaps of insight, just as it can help a nonlinear thinker to reason critically about a complex problem. Both dimensions are essential for the whole student.

James Zull, mentioned earlier, asks: given what we know about how the brain works, how should we change how we teach? This is a problem of central importance for every faculty member and student, and Zull draws on his own teaching experience at Case Western Reserve University to argue that active learning and active testing can strengthen our teaching, while engaging still another part of our brain. For example, he describes the role of the motor cortex in initiating action, and the surprising result that the small but highly connected cerebellum, thought to be associated with subconscious process, is also activated by speaking words connected with verbs of action. He also argues that concrete metaphors help introduce abstract concepts to a class: "Metaphors are sets of neuronal networks that possess specific physical relationships to each other in the brain and thus embody the concept of the relationship itself. . . . This is why metaphors, parables, and stories are so powerful when we want to teach a concept."[13]

Metaphor is a deep and powerful concept for understanding how we think, and especially how we relate different areas and concepts to one another. The word itself comes from a Greek root meaning "carrying across," and is a central concept in literary analysis, where metaphor is a figure of speech in which "a name or descriptive word or phrase is transferred to an object or action different from, but analogous to, that to which it is literally applicable."[14] In a broader sense, metaphor is connected to interdisciplinary work, in which ideas and frameworks from one field are carried over into another. The work of cognitive linguist George Lakoff has been particularly important for the philosophical study of metaphor and language, emphasizing how metaphor maps abstract conceptual domains onto concrete perceptual images.[15]

Metaphor enters into science in numerous ways. In his essay on this subject, historian of science Thomas Kuhn writes that "Metaphor plays an essential role in establishing links between scientific language and the world. Those links are not, however, given once and for all. Theory change, in particular, is accompanied by a change in some of the relevant metaphors."[16] These ideas have been expanded by chemist Theodore Brown in his book, Making Truth: Metaphor in Science.[17] Brown quotes physicist Ludwig Boltzmann: "How awkward is the human mind in divining the nature of things, when forsaken by the analogy of what we see and touch directly."[18] From chaperone molecules in biochemistry to protein folding, Brown argues, abstract scientific concepts are shaped by the concrete metaphors used to describe them. Another example is the famous story that organic chemists tell, that August Kekulé discovered the structure of benzene by means of a dream in which he saw snakes chasing each other in circular loops. Brown argues that metaphor is vital for science education: to make science compelling to young people, it needs to connect to real life experience through metaphor.[19]

The most interesting questions Brown poses (but does not fully answer) are these: "What are the origins of scientific creativity? Armed with the recognition that most of scientific reasoning is embodied and grounded in metaphor, can we do specific things to stimulate creativity?"[20] I would argue that the most creative people are those who are capable of connecting concepts and images across large domains of knowledge, inside and outside of science, and that a broad liberal education helps to stimulate the ability of the brain to make such connections.

My former colleague at the University of Chicago, Martha Nussbaum, has written eloquently about the place of the humanities in a liberal education and in our modern society, as exemplified by her fine book, Not for Profit: Why Democracy Needs the Humanities.[21] I would like to develop some thoughts about the connections between the humanities and the sciences from the point of view of a scientist who is passionate about art, music, literature, and philosophy. During a recent sabbatical at Cambridge University, I spent my time doing research in biophysical chemistry, auditing courses in philosophy and the history of science, and immersing myself in the musical culture of Britain. These experiences led me back to thinking about a familiar topic, the cultural divide between the sciences and the humanities in the modern world. On May 7, 1959, the British scientist and novelist C. P. Snow presented a now famous talk at the Senate House at Cambridge, just down the street from Trinity College where I spent my sabbatical. Titled "The Two Cultures and the Scientific Revolution," his lecture was subsequently published as a book that has stimulated considerable discussion, with both support and criticism of his hypothesis.[22]

At the heart of the Snow's work is the contention that education at the time (particularly in Britain) was divided in such a way that too many educated people knew the classics of literature but not the basic principles of science. In a memorable passage, Snow relates, "A good many times I have been present at gatherings of people who, by the standards of the traditional culture, are thought highly educated and who have with considerable gusto been expressing their incredulity at the illiteracy of scientists. Once or twice I have been provoked and have asked the company how many of them could describe the Second Law of Thermodynamics. The response was cold: it was also negative. Yet I was asking something which is about the scientific equivalent of: *Have you read a work of Shakespeare's?*"

This statement still resonates today. Despite the high esteem in which modern science is held, with discoveries such as the Higgs boson and developments in modern genetics drawing front-page headlines, there is still a woeful lack of understanding of the principles of science, even among well-educated citizens. This has serious consequences for our ability as a society to make thoughtful and fact-based judgments about difficult policy issues involving science and technology. Consider for example the absurd public debate still underway in this country and elsewhere about whether climate change is real.

And yet Snow's core argument, that British education, in contrast to American and German, privileged the classics relative to science and engineering seems quaintly out of date today. I would argue, with many other commentators, that there is now a serious and growing problem in the opposite direction. Narrow teaching oriented toward test-taking has forced out much of the coursework connected to reading and engaging deeply with the great works of literature; budget cuts have eliminated art, music, and theater courses in many of our schools; and the national policy discussion tends to focus on STEM education. As students reach college, they are focused on an "instrumental" view of education, in which the courses they take are directly connected to jobs they will qualify for upon graduation. Many of the broad skills of a liberal education are connected to the humanities, including the ability to write and speak effectively, to analyze complex problems from many points of view, to think visually, and to understand different global perspectives.[23]

In a recent article,[24] I called attention to the renewed importance not only of the "book oriented" humanities such as literature, philosophy, and art and music history, but also to the role of the creative and performing arts in a liberal education. I argued that by integrating arts practice and arts experience at the heart of our curricula as well as the environment and life of our campuses, we help to create more engaged citizens, we encourage all students to push their personal boundaries, we foster embodied and experiential education, and we instill the capacity for innovation.[25]

Moreover, the arts and humanities work toward developing what Daniel Pink, in A Whole New Mind, calls the "six senses:" Design, Story, Symphony, Empathy, Play, and Meaning.[26] These are the "high-concept, high-touch" aptitudes that "help develop the whole new mind" demanded by the "Conceptual Age" into which we are shifting from the previous "Information Age." I would connect them, literally or metaphorically, to core disciplines in the humanities: Art, Creative Writing (but also History), Music, Literature, Theatre and Dance, and Philosophy and Religion.

In one of his delightful passages, Pink observes, "Back on the savannah, our cave person ancestors weren't taking SATs or plugging numbers into spreadsheets. But they were telling stories, demonstrating empathy, and designing innovations."[27] Part of the new age into which we have entered thus brings us back to the earliest days of humanity and the evolution of the human brain's capacity to respond to our surroundings.

I don't want to trivialize the disciplines of the humanities by making them the subject matter of pop psychology or easy classifications; humanities disciplines have depth, rigor, and bodies of scholarly production and performance that speak for themselves. And a recent report by the

Commission on Humanities and Social Sciences of the American Academy of Arts and Sciences makes clear the critical importance of the humanities and social sciences to an informed and engaged citizenry.[28] To push even further, I would argue that we should think of Pink's six senses, which for him characterize the habits of mind necessary for success in the "conceptual age," and which seem to resonate particularly with the humanities and arts, in relation to teaching and learning in the social sciences and science as well. How would it look to cultivate the "aptitudes" of Design, Story, Symphony, Empathy, Play, and Meaning in the so-called "hard" sciences?

One key goal of the college years is to teach students to deal with ambiguity. Eighteen-year-olds often arrive on our campuses with a lot of certainty in their minds, at least on the academic side if not in their personal lives. They have succeeded in finding the "right" bubbles to fill in on the SAT test. Their writing often exemplifies the rigid five-paragraph essay form (introduction, three arguments, conclusion, each with its own proper topic sentence and development), and we try to develop more flexible writing habits once they arrive. Their image of science is frequently built around the lab experiment where the goal is to come as close as possible to the "correct" answer. Without minimizing the outstanding education that many students bring from their high schools, the fact remains that a great deal of secondary education involves funneling bright students through courses in which they become adept at ending up with the known answer that their teacher is looking for. Our students believe that coming to an elite college is the pathway to success in the modern world, and they are eager to check off all the right boxes during their time on campus.

Part of our job as college teachers is to shock students out of the certainties that they bring, to surprise them with new ideas, and to show them that interesting questions usually do not have simple answers: in short, to teach them to deal with ambiguity. Let me take an example from my introductory chemistry class. Chemists like to characterize substances as ionic or covalent: sodium chloride is ionic, as seen by the fact that it dissolves to form a solution that conducts electrical current, while oxygen is covalent, with equal sharing of electrons between the two atoms in the molecule. A deeper study shows, though, that every substance has at least some ionic and some covalent character, and many really just fall somewhere in between. The simple concepts taught in elementary chemistry are still useful, but the classification is no longer quite as straightforward.

In his book on art and the mind, Eric Kandel writes, "Paintings engage us, in part, by creating ambiguity." He notes that not only does a painting draw different responses from different observers – there is no one "correct" way to see it – but even a single observer sees it differently at different moments. "Our relationship with a painting involves a continuous, unconscious adjustment of our feelings as our eye movements scan the work." Kandel quotes art historian Ernst Gombrich, who observed on viewing Leonardo's Mona Lisa that she looks "like a living being changing in front of our eyes." Great art, like great literature, is subject to multiple meanings, multiple interpretations.[29]

The same is true of other fields as well. One of the goals of a Socratic dialog, which forms the basis for many of our discussion-based classes, is to challenge the interpretations each student brings in by exploring other points of view. If a class discussion seems to be heading toward some particular consensus, a good teacher will often try to raise objections and cause students to question both their assumptions and their conclusions. A healthy dose of skepticism about simple answers to complex problems is one of the most valuable products of a liberal education. We certainly do not want to produce graduates who are paralyzed by doubt, but we do want them to emerge with an understanding that ambiguity is a central part of life.

Finally, let me conclude by connecting several key concepts I have addressed here, by developing an extended metaphor that relates a liberal arts education to order, chaos, and the Second Law of Thermodynamics.

Life exists between the two poles of order and chaos. At the one extreme, complete order is represented by a low-temperature crystal in which almost every atom is in its proper place. This crystal is elegantly symmetric, simple to describe, and completely stable: all good qualities. But it is also boring: there is no activity, no change, no deeper interest to this state of matter. At the other extreme, the chaotic state is exemplified by a gas at high temperature. Here, all the molecules are flying around at great speed, there is a lot of activity, but there is no purposefulness. Living systems are poised between these two extremes, with enough order to preserve complex structures and carry out metabolic processes (think about proteins and genetic material) but enough motion to actually change on a reasonable time scale. It is no wonder that life is thought to have arisen, and to persist, in the liquid state of water, between the order of ice and the disorder of hot steam.

Now the Second Law states that the entropy of a closed system always increases with time, where the entropy is a property that measures the number of states available to the atoms and molecules in the system, or more abstractly the degree of disorder in the system. In a crystalline solid, there are very few choices for the positions of each molecule and the entropy is low, while for a high-temperature gas there are many possible positions and the entropy is high. If the earth were a closed system, the second law would state that the extent of disorder would increase steadily with time, a process that moves in the opposite direction from the evolution of life and the emergence of complex living systems from simple molecules.

How can we reconcile these two observations? By the fact that the earth is not a closed system. It is bathed in light from the sun, and the photons that arrive from the outside provide the energy that allows living processes to take place. Put another way, the earth and the sun are coupled systems, so that if the entropy of the sun increases sufficiently (through nuclear fusion reactions) the entropy of the earth can decrease. As long as the sun continues to burn, life on earth, with its organizing tendencies toward greater order, can persist and, indeed, thrive.

In a metaphoric sense, we can think of education in a parallel way. As learners, we stand poised between order and chaos. At the one extreme is the simple order of rigid laws; at the other is the chaos of random and unfocused ideas. In between is the "sweet spot" where the two are balanced and we are able to work within constraints in creative ways. But we cannot move forward as isolated individuals; for that we need the combined forces of multiple disciplines and ways of learning.

I have done some research in the area of crystal growth, trying to understand the rate of growth of crystals from the melt. It turns out that the condition that selects for maximum growth is one of "marginal stability", namely the stable condition that is closest to the border of chaos. I like this observation. It suggests that to maximize our own growth we should always be pushing ourselves to the edge, challenging our desire for simplicity and order and moving from simple answers to complex questions. In thinking about how the brain works, this concept of "marginal stability" might relate to the observation that creative genius and madness often can be connected in even tragic ways. Brilliant scientists, writers, and artists living on the edge of chaos can, sadly, sometimes pass over that boundary.

Maybe genius and madness are not in the cards for all of us, and that is probably for the best. There is plenty of opportunity for creative expression and innovative ideas at some distance from the border of chaos. The purpose of a liberal education is to develop habits of mind that rely on hard work and discipline on the one hand and creative inspiration on the other. A liberal education should provide the environment, the tools, and the community that encourage students to work hard and to learn about as many fields as possible, but also to explore the unexpected connections between disparate fields that can predispose the brain to inspiration throughout their lives. As higher education leaders, it is a time to rededicate ourselves to that goal in new and creative ways.

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[2] Daniel H. Pink, A Whole New Mind: Why Right-Brainers Will Rule the Future (New York: Riverhead Books, 2006), 22.

[3] Hanna Rosin, "The End of Men," The Atlantic (July/August 2010), http://www.theatlantic.com/magazine/archive/2010/07/the-end-of-men/308135/. See now Hanna Rosin, The End of Men: And the Rise of Women (New York: Riverhead Books, 2012).

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