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Three Types of Creativity

The chief enemy of creativity is good sense.

—PABLO PICASSO

The value placed on creativity in modern times has led to a range of writers and thinkers trying to articulate what it is, how to stimulate it, and why it is important. It was while serving on a committee convened by the Royal Society to assess what impact machine learning would likely have on society that I first encountered the theories of Margaret Boden.

Boden is an original thinker who over the decades has managed to fuse many different disciplines: she is a philosopher, psychologist, physician, AI expert, and cognitive scientist. In her eighties now, with white hair flying like sparks and an ever-active brain, she enjoys engaging with the question of what these "tin cans," as she likes to call computers, might be capable of. To this end, she has identified three different types of human creativity.

Exploratory creativity involves taking what is already there and exploring its outer edges, extending the limits of what is possible while remaining bound by the rules. Bach's music is the culmination of a journey that baroque composers embarked on to explore tonality by weaving together different voices. His preludes and fugues pushed the boundaries of what was possible before breaking the genre open and ushering in the classical era of Mozart and Beethoven. Renoir and Pissarro reconceived how we could visualize nature and the world around us, but it was Claude Monet who really pushed the boundaries, painting his water lilies over and over until his flecks of color dissolved into a new form of abstraction.

Mathematics revels in this type of creativity. The classification of Finite Simple Groups is a tour de force of exploratory creativity. Starting from the simple definition of a group of symmetries—a structure defined by four simple axioms—mathematicians spent 150 years compiling the list of every conceivable element of symmetry. This effort culminated in the discovery of the Monster simple group: it has more symmetries than there are atoms in the Earth and yet fits into no pattern of other groups. This form of mathematical creativity involves pushing limits while adhering strictly to the rules of the game. Those who engage in it are like the geographical explorers who, even as they discover previously unknown territory, are still bound by the limits of our planet.

Boden believes that exploration accounts for 97 percent of human creativity. This is also the sort of creativity at which computers excel. Pushing a pattern or set of rules to an extreme is a perfect exercise for a computational mechanism that can perform many more calculations than the human brain can. But is it enough to yield a truly original creative act? When we hope for that, we generally imagine something more utterly unexpected.

To understand Boden's second type, *combinational creativity*, think of an artist taking two completely different constructs and finding a way to combine them. Often the rules governing one will suggest an interesting new framework for the other. Combination is a very powerful tool in the realm of mathematical creativity. The eventual solution of the Poincaré conjecture, which describes the possible shapes of our universe, was arrived at by applying the very different tools used to understand flow over surfaces. In a leap of creative genius, Grigori Perelman landed at the unexpected realization that by knowing the way a liquid flows over a surface one could classify the possible surfaces that might exist.

My own research takes tools from number theory that have been used to understand primes and applies them to classify possible symmetries. The symmetries of geometric objects don't look at first sight anything like numbers. But applying the language that has helped us to navigate the mysteries of the primes and replacing primes with symmetrical objects has revealed surprising new insights into the theory of symmetry.

The arts have also benefited greatly from this form of cross-fertilization. Philip Glass took ideas he learned from working with Ravi Shankar and used them to create the additive process that is the heart of his minimalist music. Zaha Hadid combined her knowledge of architecture with her love of the pure forms of the Russian painter Kasimir Malevich to create a unique style of curvaceous buildings. In cooking, creative master chefs have fused cuisines from opposite ends of the globe.

There are interesting hints that this sort of creativity might also be perfect for the world of AI. Take an algorithm that plays the blues and combine it with the music of Boulez and you will end up with a strange hybrid composition that might just create a new sound world. Of course, it could also be a dismal cacophony. The coder needs to find two genres that can be fused algorithmically in an interesting way.

It is Boden's third form of creativity that is the more mysterious and elusive. What she calls *transformational creativity* is behind those rare moments that are complete game changers. Every art form has these gear shifts. Think of Picasso and cubism. Schoenberg and atonality. Joyce and modernism. They are phase changes, like when water suddenly goes from liquid to gas or solid. This was the image Goethe hit upon when he sought to describe how he was able to write *The Sorrows of Young Werther*. He devoted two years to wrestling with how to tell the story, only for a startling event, a friend's suicide, to act as a sudden catalyst. "At that instant," he recalled in *Dichtung und Wahrheit*, "the plan of *Werther* was found; the whole shot together from all directions, and became a solid mass, as the water in a vase, which is just at the freezing point, is changed by the slightest concussion into ice."

At first glance it would seem hard to program such a decisive shift, but consider that, quite often, these transformational moments hinge on changing the rules of the game, or dropping a long-held assumption. The square of a number is always positive. All molecules come in long lines, not chains. Music must be written inside a harmonic scale structure. Eyes go on either sides of the nose. There is a meta rule for this type of creativity: start by dropping constraints and see what emerges. The creative act is to choose what to drop—or what new constraint to introduce—such that you end up with a new thing of value.

If I were asked to identify a transformational moment in mathematics, the creation of the square root of minus one, in the mid-sixteenth century, would be a good candidate. This was a number that many mathematicians believed did not exist. It was referred to as an imaginary number (a dismissive term first used by Descartes to indicate that there was no such thing). And yet its creation did not contradict previous mathematics. It turned out it had been a mistake to exclude it. Now consider, if that error had persisted to today: Would a computer come up with the concept of the square root of minus one if it were fed only data telling it that there is no number whose square could be negative? A truly creative act sometimes requires us to step outside the system and create a new reality. Can a complex algorithm do that?

The emergence of the romantic movement in music is in many ways a catalog of rule-breaking. Instead of hewing to close key signatures as earlier composers had done, upstarts like Schubert chose to shift keys in ways that deliberately defied expectations. Schumann left chords unresolved that Haydn or Mozart would have felt compelled to complete. Chopin composed dense moments of chromatic runs and challenged rhythmic expectations with his unusual accented passages and bending of tempos. The move from one musical era to another, from Medieval to Baroque to Classical to Romantic to Impressionist to Expressionist and beyond, is one long story of smashing the rules. It almost goes without saying that historical context plays an important role in allowing us to define something as new. Creativity is not an absolute but a relative activity. We are creative within our culture and frame of reference.

Could a computer initiate the kind of phase change that can move us into a new state? That seems a challenge. Algorithms learn how to act based on the data presented to them. Doesn't this mean that they will always be condemned to producing more of the same?

As the epigraph of this chapter, I chose Picasso's observation that the "chief enemy of creativity is good sense." That sounds, on the face of it, very much against the spirit of the machine. And yet, one can program a system to behave irrationally. One can create a meta rule that will instruct it to change course. As we shall see, this is in fact something machine learning is quite good at.

Can Creativity Be Taught?

Many artists like to fuel their own creation myths by appealing to external forces. In ancient Greece, poets were said to be inspired by the muses, who breathed a kind of creative energy into their minds, sometimes sacrificing the poet's sanity in the process. For Plato, "a poet is holy, and never able to compose until he has become inspired, and is beside himself and reason is no longer in him . . . for no art does he utter but by power divine." The great mathematician Srinivasa Ramanujan likewise attributed his insights to ideas imparted to him in dreams by the goddess Namagiri, his family's deity. Is creativity a form of madness or a gift of the divine?

One of my mathematical heroes, Carl Friedrich Gauss, was known for covering his tracks. Gauss is credited with creating modern number theory with the publication in 1798 of one of the great mathematical works of all time: the *Disquisitiones arithmeticae*. When people tried to glean from his book just how he got his ideas, they were mystified. It has been described as a book of seven seals. Gauss seems to pull ideas like rabbits out of a hat, without ever really giving us an inkling of how he conjured them. At one point, when someone asked him about this, he retorted that an architect does not leave up the scaffolding after the house is complete. He attributed one revelation to "the Grace of God," saying he was "unable to name the nature of the thread" that connected what he had previously known to the subsequent step that made his success possible.

Just because artists are often unable to articulate where their ideas come from does not mean they follow no rules. Art is a conscious expression of the myriad logical gates that make up our unconscious thought processes. In Gauss's case, there was a thread of logic that connected his thoughts. It's simply that it was hard for him to articulate what he was up to—or perhaps he wanted to preserve the mystery and boost his image as a creative genius. Coleridge's claim that the drug-induced vision of *Kubla Khan* came to him in its entirety is belied by all the evidence of preparatory material, showing that he worked up the ideas before that fateful day when he was interrupted by the person from Porlock. Of course, the white-hot flash of inspiration makes for a good story. Even my own accounts of creative discovery focus on that dramatic moment rather than the years of preparatory work I put in.

We have an awful habit of romanticizing creative genius. The solitary artist working in isolation is frankly a myth. In most instances, what looks like a step change is actually continuous growth. Brian Eno talks about the idea of *scenius*, not genius, to acknowledge the community out of which creative intelligence often emerges. Joyce Carol Oates agrees: "Creative work, like scientific work, should be greeted as a communal effort—an attempt by an individual to give voice to many voices, an attempt to synthesize and explore and analyze."

What does it take to stimulate creativity? Might it be possible to program it into a machine? Are there rules we can follow to become creative? Can creativity, in other words, be a learned skill? Some would say that to teach or program is to show people how to imitate what has gone before, and that imitation and rule-following are incompatible with creativity. Yet, we have examples of creative individuals all around us who have studied and learned and improved their skills. If we study what they do, could we imitate them and ultimately become creative ourselves?

These are questions I find myself asking anew every semester. To receive a PhD, a doctoral candidate in mathematics must create a new mathematical construct. He or she has to come up with something that has never been done before. I am tasked with teaching my students how to do that. Of course, at some level, they have been training to do this from their earliest student days. Solving a problem calls for personal creativity even if the answer is already known.

That training is an absolute prerequisite for the jump into the unknown. Rehearsing how others came to their breakthroughs builds the capacity to achieve one's own creative feats. Boden distinguishes between what she calls "psychological creativity" and "historical creativity." Many of us achieve acts of personal creativity that may be novel to us but historically old news. These are what Boden calls moments of psychological creativity. It is by repeated acts of personal creativity that ultimately one hopes to produce something that is recognized by others as new and of value. To be sure, that jump is far from guaranteed. But while historical creativity is rare, when it does occur, it emerges from encouraging psychological creativity.

I can't take just anyone off the street and teach them to be a creative mathematician. Even if I had ten years to train them, we might not get there—not every brain seems to be able to achieve mathematical creativity. Some people appear to be able to achieve creativity in one field but not another, yet it is difficult to understand what sets one brain on the road to becoming a chess champion and another, a Nobel Prize–winning novelist.

My recipe for eliciting original work in students follows Boden's three types of creativity. Exploratory creativity is perhaps the most obvious path. This involves deep immersion in what we have created to date. Out of that deep understanding might emerge something never seen before. It is important to impress on students that there isn't very often some big bang that resounds with the act of creation. It is gradual. Van Gogh expressed it well: "Great things are not done by impulse but by small things brought together."

I find Boden's second type, combinational creativity, to be a powerful weapon in stimulating new ideas. I often encourage students to attend seminars and read papers in subjects that don't seem connected with the problems they are tackling. A line of thought from a distant corner of the mathematical universe might resonate with the problem at hand and stimulate a new idea. Some of the most creative bits of science are happening today at the junctions of the disciplines. The more we can stray beyond our narrow lanes to share our ideas and problems, the more creative we are likely to be. This is where a lot of the low-hanging fruit is found.

Boden's third type, transformational creativity, seems hard at first sight to harness as a strategy. But again, the goal is to test the status quo by dropping some of the constraints that have been put in place. Try seeing what happens if you change one of the basic rules you have accepted as part of the fabric of your subject—it's dangerous, because by doing so you can collapse the system. But this brings me to one of the most important ingredients needed to foster creativity, and that is embracing failure.

Unless you are prepared to fail, you will not take the risks that will allow you to break out and create something new. This is why our education system and our business environment, both realms that abhor failure, are terrible environments for fostering creativity. If I want creativity from my students, I have learned, it is important to celebrate their failures as much as their successes. Sure, their failures won't make it into the PhD thesis, but so much can be learned from them. When I meet with my students, I repeat again and again Samuel Beckett's call to "Try. Fail. Fail again. Fail better."

Are these strategies that can be written into code? In the past, the top-down approach to coding meant there was little prospect of creativity in the output. Coders were never very surprised by what their algorithms produced. There was no room for experimentation or failure. But this all changed recently—because an algorithm, built on code that learns from its failures, did something that was new, shocked its creators, and had incredible value. This algorithm won a game that many believed was beyond the abilities of a machine to master. As we will see in Chapter 3, it was a game that required creativity to play.