Accident, Intention, and Expectation in Innovation Process

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ABSTRACT

This paper elaborates upon the observation, frequent in histories of human accomplishment, that fortuitous accidents play a role in discovery and invention. We present evidence from interviews with artists to suggest that accident might be generally important to innovation process. We derive implications for business firms from this hypothesis. The interview data portray a process that incorporates accident and contrasts with the process representations and prescriptions of management researchers and other scientists. We consider the possibility that models in which accident plays a large role (that is, models which more closely align with the process representations of artists) are more accurate and less idealized, and we discuss the implications of this possibility for managers.

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INTRODUCTION

In the 1830s, Louis Jacques Mande Daguerre developed the technique for capturing visual images on physical media later known as "photography." By exposing a silver-coated copper plate to iodine vapor, he formed a thin layer of silver iodide on the surface. Using a "camera obscura," he exposed the plates to light and produced a faint image. In the early stages of his work, he could not intensify the image.

One day he happened to place a plate bearing a faint image into a cabinet, intending to clean it later. When he took the plate out of the cabinet, he found the image greatly improved. Daguerre hypothesized that one or more vaporous chemicals stored in the cabinet had intensified the image.

He began experiments to determine which chemicals were responsible, placing new plates in the cabinet and removing chemicals one by one. Eventually all chemicals had been taken away but the intensification of images still occurred. Perplexed, Daguerre examined the cabinet itself. He found on one shelf a few drops of mercury spilled from a broken thermometer and concluded, correctly, that mercury vapors were responsible for the improved images (Roberts, 1989).[1]

This narrative notably illustrates the interplay between planned experimentation and accident in the process of creating value through innovation. Daguerre's process was carefully designed at many points, but his great discovery also depended on unplanned events: the incidental decision to store the plate in the cabinet; the contemporaneous shattering of a thermometer; the failure to notice (or at least thoroughly clean up) the resulting mercury spill. Some of these events were arguably, as Mach (1896) has put it, "beyond foresight"; they could not have been planned.

Accounts of beyond-foresight events important in invention or discovery are common. Anesthesia, cellophane, corn flakes, dynamite, nylon, penicillin, PVC, rayon, smallpox vaccine, stainless steel, and Teflon are just a few examples of innovations that

[1] See http://www.wfu.edu/users/corbsp1/project.htm.

involved accident. Alexander Fleming's remarks at the 1945 Harvard University Commencement provide his sense of the importance of accident:

> I did not ask for a spore of penicillium notatum to drop on my culture plate…When I saw certain changes, I had not the slightest suspicion that I was at the beginning of something extraordinary…. That same mould might have dropped on [any one] of my culture plates, and there would have been no visible change to direct special attention to it (Rudenstein, 1995).

Fleming's remarks are far from atypical. Many innovators acknowledge the role that chance plays in achieving valuable outcomes. Mach, himself a scientist of note, asserted that "most important inventions are brought to man's attention accidentally" (1896)—a strong and controversial claim, but undeniably important if true.

Whether accidental innovation is the exception or the rule, the question of how much importance should be attributed to accidents when they do occur, and the larger question of the role of accident in human progress, have been fiercely debated. Some have viewed efforts to credit creative outcomes to accident as attempts to diminish the contributions of innovators (e.g., Whewell, 1837, Rossman, 1931, Gilfillan, 1935). Vladimir Lenin interpreted Mach's insistence on the importance of accident as an effort to undermine the deterministic basis of Marxist theories. (In 1908, Lenin formally declared war on all "Machists;" Merton, 2004). Indeed, questions about the importance of accident in human affairs have moral or religious implications, to the extent that they impact notions of deservingness, the predictability of the universe, or the omnipotence and intentions of deities. The tendency of questions about accident in innovation to align with hotly debated ideological issues has, no doubt, contributed to the difficulty thinking clearly about them.

We don't intend to resolve these matters in this paper. Indeed, we approach these questions with some trepidation, to accomplish three simple tasks.

First, we propose a way to examine the hypothesis that accident is important in creative process. How often do accidents play a role in important innovations? Careful consideration of this question requires that we develop a concept of degree of accident, which we call "accident intensity." Narrative accounts of accident in the history of discovery and invention demonstrate that not all accidents are equally "accidental." The word, as casually

used, is not sufficiently precise. To address this problem, we propose a framework for classifying the intensity of accidents that, although still rough, adds a measure of precision to the idea, "accident." While we do not in this paper use our scale to arrive at definitive conclusions with respect to the large topic of accidental innovation in business, we've presented it so as to suggest a structure for ongoing discussion.

Second, we propose an "accident-friendly" process for business innovation based on Campbell's (1960) evolutionary model of creative process as a combination of blind variation and selective retention. Through interviews with artists, and systematic observation of their work, we identify strategies they use for achieving and retaining useful variation. From these interviews we derive a process framework for achieving creative outcomes that incorporate accident. These data are helpful also in identifying associated factors and (especially) antecedents involved in creative process, such as attitudes toward failure and similarities of motivation by innovators.

Third, we begin to characterize a capability for absorbing accident effectively into creative process. Louis Pasteur's statement that "chance favors the prepared mind" has been often cited in response to the observation that accident plays an important role in creative outcomes. As Mach and others have argued, events considered accidental antecedents to major innovations had often occurred many times before someone recognized their importance. As Cannon (1940) put it, many floated in water before Archimedes, many saw apples fall before Newton, and many suffered pots boiled over on hot stoves before James Watt. But prepared minds turned those accidents into great achievements.

The idea that important innovation requires preparation finds eager expression in the arts. We found in our interviews that artists believe in an acquired skill for recognizing useful accidents. Perhaps more important, they also believe they can acquire a skill at *generating* useful accidents. At least some of science and business practice appears to diverge from arts practice at this point. Whereas the famous helpful accidents in science and business usually "just happened," accidents in the arts often result from artists deliberately injecting randomness into their processes, in hopes of creating good but unexpected outcomes. We

consider whether this difference reflects essential differences between art and business, or whether it might suggest to some innovators a direction for improvement.

AN ACCIDENT INTENSITY SCALE

As commonly used, the word "accident" describes a broad idea; dictionary definitions center on "lack of intention" as the essential characteristic of an accident, but also often add "unforeseen" or "undesirable" as additional attributes.[2] In our discussion of *fortuitous* accidents, we disregard the "undesirable" connotation for obvious reasons, but the degree and direction of intention, and thus the degree to which events might reasonably be foreseen, are central to the development of our scale of accident intensity.

When you read accounts of accidents involved in discovery and invention, you quickly realize that not all accidents are equal. Encountering your neighbor at a grocery store near your home in Copenhagen, assuming that neither of you intended the meeting, is unlikely and thus happens "by accident;" but it seems a much greater accident to encounter the same neighbor, again without intending to, on the streets of Tokyo. Accidents range from random mental associations that further the pursuit of a current objective to unlikely coincidences of random events that create value not even sought. This sense of difference in accidents suggests a rough scale.

The scale we propose is not the only possible scale, and we make selective and specific claims about its usefulness. We don't claim greater importance or greater impact on human progress for accidents that measure higher on the scale. That's an open question that the scale might assist in resolving. Nor do we claim—and this is very important because it is a source of much controversy in debates about the role of accident in human progress—that accident is *primarily* responsible for the progress that was made in a particular instance. In pointing to accidents in particular stories, we observe merely that accident seemed present in an important way, not that the outcome would never have been achieved without the accident,

[2] See, for example, the The American Heritage® Dictionary of the English Language: Fourth Edition. 2000, http://www.bartleby.com/61/7/A0040700.html.

or that the accident was more important than the intentional work that came before it or afterward built upon it. We intend with our intensity scale merely to capture a subjective sense of just how accidental a particular event might seem, and to correct partially for the imprecision in the loose use of the word "accident" in popular accounts of discovery and invention. To arrive at a sense of an accident's intensity, we point to the aspect of accident most often cited as essential: lack of intention. The less an intention aligned with the accidental outcome, the higher the accident's intensity on our scale.

Level 1 Accidents – Unlikely Mental Associations

The story of how August Kekule von Stradonitz, one of the founders of structural organic chemistry, arrived at an understanding of the shape of the benzene molecule (a ring), helps us define a "Level 1" accident. Kekule recalled the moment:

> I was sitting writing on my textbook, but the work did not progress; my thoughts were elsewhere. I turned my chair to the fire and dozed…the atoms were gamboling before my eyes…My mental eye, rendered more acute by repeated visions of the kind, could now distinguish larger structures of manifold conformation: long rows sometimes more closely fitted together all twining and twisting in snake-like motion. But look! What was that? One of the snakes had seized hold of its own tail, and the form whirled mockingly before my eyes. As if by a flash of lightning I awoke… and spent the rest of the night working out the consequences of the hypothesis (Gratzer, 2002).

Adolf von Bayer, among the most highly regarded of history's organic chemists, once said he would have exchanged his lifetime's accomplishments for this one brilliant insight of Kekule's (Gratzer, 2002).

As impressive as this insight might have been, however, it rates as modestly accidental on our scale. Kekule was working to understand the structure of the benzene molecule when he had his dream. Although the way he got there had an accidental quality, it aligned with both the general sense of his activity—he was looking for something and found something—and also with the specific objectives of his activity—it was the structure of the benzene molecule he aimed to discover, and that is, in fact, what he did discover. The accidental event in this case lined up with the investigator's intentions, and was within range of his reasonable expectations. If the insight had not appeared to Kekule in a dream, it might

have eventually occurred to him in a conscious state; or he might even have found it through trial and error examination of different structures. Those wouldn't be accidents. On our proposed scale, Kekule's dream is the mildest sort of accident—which does not, we repeat, suggest a lack of importance.

Indeed, there are accidents of great significance in this category. Edward Jenner's insight that led to a smallpox vaccine resulted from his idle recollection of a milkmaid saying, when he was 19 years old, "I shall never have smallpox for I have had cowpox; I shall never have an ugly pockmarked face." (Rodenberg, 2005). This recollection, summoned in the midst of Jenner's inquiry to understand and treat smallpox, qualifies as a Level 1 accident on our scale, but it had tremendous importance for medicine.

Level 2 Accidents – Looking for something, found it in an unexpected way

This account from the *Wall Street Journal* describes a level 2 accident:

> In 1991, Schering-Plough scientists were looking for a drug that would block a certain cholesterol-producing enzyme in the body. They noticed in a test on hamsters that one molecule, while failing to block that enzyme, nonetheless lowered cholesterol…[the] scientists [had] stumbled onto a new approach for reducing cholesterol (Landers, 2004).

The drug developed from this serendipitous discovery was a billion dollar blockbuster.

This accident is more than a mental association, but its accidental intensity is limited: the Schering-Plough scientists looked for something and found it—a way of reducing cholesterol. But the important outcome of their search was beyond foresight because the theoretical and predictive frameworks in which the scientists were working did not anticipate this particular outcome. They were looking for a valuable result along one axis, but value appeared along a different axis, one to which they paid only incidental attention. The *Wall Street Journal* article pointed out, as part of a critique of efforts to automate drug discovery, that if this experiment had been designed in a way that did not allow notice of results along unexpected axes, it would have missed the discovery: "If a robot had tested the molecule, it would have caught the failure [to block the cholesterol producing enzyme] but missed the serendipitous side effect [lowering of cholesterol by another means]." This observation

captures perfectly the degree of accidentalness in a Level 2 intensity event; even though the accident was aligned with the sense and objectives of the intentional inquiry, it could not have been executed by an entity with no ability to notice the unexpected. To say this another way: The important outcome was consistent with the intentions of the investigators, but beyond their reasonable expectations.

Level 3 Accidents – Looking for one thing, found something else

The history of the development of artificial sweetening agents provides examples of what we call level 3 accidents. James Schlatter, an organic chemist at G. D. Searle, was working on a treatment for gastric ulcers when this happened:

> I was heating the aspartame in a flask with methanol when the mixture [boiled abruptly] onto the outside of the flask. As a result some of the powder got onto my fingers. At a slightly later stage, when licking my fingers to pick up a piece of paper, I noticed a very strong, sweet taste…I traced the powder on my hands back to the container into which I had placed the crystallized aspartylphenylalanine methyl ester. I felt that this dipeptide ester was not likely to be toxic and I therefore tasted a little of it and found it was the substance which I had previously tasted on my finger (Gratzer, 2002).

Schlatter was looking for something, but he found a valuable thing entirely different from what he was seeking. Thus, the general sense of his intention lined up with the outcome, but his specific objectives and the outcome had no relationship at all. He looked for an ulcer treatment and discovered a food sweetener--absolutely unpredictable, hence remarkable to our subjective sensibilities.

The history of sweeteners offers other examples of Level 3 accidents. In 1937, a research student was smoking in the laboratory while he worked to find a drug to prevent or reduce fever. When he took a drag from his cigarette, which had been resting on the end of the lab bench, he experienced the sensation of sweetness, which ultimately led the lab to cyclamate sweeteners (Gratzer, 2002). The researcher sought a specific thing, but quite by accident found something quite different and valuable.

The example of another sweetener, sucralose, helps us consider nuances between level 2 and level 3: In 1976, a foreign research student at King's College in London was

helping Professor L. Hough find industrial applications of sucrose, the common sugar derived from cane and beets. One derivative was a trichlorosucrose, which Hough asked the student to "test." The foreign student, for whom the sound of English was new, heard "test" as "taste;" the result was sucralose, a powerful sweetening food additive (Gratzer, 2002). The investigator looked for something, and found in an unexpected way something closely related to what he sought. But depending on how close you consider the alignment between Professor's Hough's intentions to find industrial applications for one food additive and the discovery of another, you might consider this to be either a level 2 or level 3 accident, perhaps something in between.

Level 4 Accidents – Not looking for anything, found something valuable

The invention of cornflakes in 1894 by John Kellogg, a medical doctor supervising a famous hospital and health spa in Michigan, and his brother Will, business manager of the facility, provides an example of what we term a level 4 accident. The hospital served patients a restricted diet intended to eliminate harmful substances. The brothers invented many foods made from grains, including a kind of granola they made by forcing dough through rollers. One day, busy with some other matter, they left cooked wheat untended for more than 24 hours. When they returned their attention to the neglected dough, they decided to try running it through the rollers even though they knew it was stale. Instead of the long sheets they expected, the rollers produced flat flakes. These baked into a fine cereal. The brothers tried the same thing with corn and arrived at a new corn-based breakfast food (Roberts, 1989).

The events that led to the Kellogg brothers' new cereal didn't aim at inventing or discovering anything; they were mere neglect, a mistake, mismanagement of a routine activity. Lack of alignment with intention or expectation puts these events at Level 4.

Uses of the Accident Intensity Scale

One possible use for this scale is to examine the relationship between the independently judged importance of discoveries and inventions, and the intensity of the accidents (if any) involved. Hypotheses in both directions could be interesting.

We have intentionally used examples that decline along a subjective scale of importance. Kekule's insight into benzene and Jenner's smallpox vaccine involved low intensity accidents, but arguably had greater historical significance than the development of a cholesterol reducing drug, or sweetener, or new breakfast cereal, even though the latter involved higher intensity accidents. The hypothesis that outcomes of greater importance often involve *less* accident intensity leads to thoughts about the difficulty of building upon accidents that are poorly aligned with intentions. People who are not looking for what they stumble upon might not be not well positioned to maximize value from it. In contrast, a scientist set up to look into a specific matter is well positioned to exploit an accidental occurrence that is well aligned with her or his intentions. This supposition is consistent too with the idea, popular in some quarters, that as a field of science matures, making it more possible to work toward valuable outcomes in an orderly, logical way, accidents become less important in arriving at valuable discoveries.

The opposite hypothesis—Mach's view that most important inventions are brought to man's attention accidentally—is in many ways also compelling. New things discovered or created that are well aligned with intention and expectation are not likely to be all that new. If you find something you are looking for exactly where you expected to find it, how new can it be? And how much new value can you expect it to generate? Most definitions of creativity emphasize dimensions of novelty and value (determined by whatever criteria: economic, scientific, aesthetic), and deem most creative those products that are both very new and very valuable. A not-particularly-novel outcome can be very valuable, of course. But easily found value is likely to have been found already or will quickly be found by others. Differentiation—the ability to achieve value that is not available to others—is important in business innovation. We might therefore hypothesize that in business, and perhaps some other

contexts, important innovations will be more likely to be associated with high intensity accidents.

Tests of such hypotheses would need to be carefully designed. One obvious difficulty has to do with reports of the historical events surrounding discoveries or inventions. Tales of accident in discovery and invention have an appealing drama about them that might get more dramatic in the telling and retelling. For many important contributions, the original sources (e.g., Kekule, Jenner) are no longer with us. Even when an investigator can be interviewed, we rightly worry about the vagaries and biases of memory.

We would be right, too, to look at the ways people observe accidents. Accounts of innovations that do not include accident might nevertheless have accidents embedded within them. For example, suppose a chemist derives an important result without an obvious accident, but she acquired the necessary skill in a graduate school course she almost didn't take; is that an accident (whether or not it was reported in narrative accounts of the innovation)? What if an innovator slipped and narrowly avoided breaking his leg on the day in which he made a great discovery, and might well have been in the hospital instead that day? We can partially correct for this difficulty by focusing on the events most directly related to the discovery or invention, but concerns remain, especially when innovations unfold over time. What should be the time boundaries within which we search for evidence of accident? And how do we know there were not unreported accidents, perhaps not even known by the investigator, which aided in the discovery?

Translating a finding that great innovations are often associated with accidents of greater or lesser intensity into a recommendation for management requires even more caution. Clearly, the proposition that innovations of high importance mostly involve accidents of high intensity does *not* (even if true) mean that most accidents of high intensity result in innovations of great importance. We might reasonably assume in this case, however, that important events often have high intensity accidents in their background. Thus it is equally clear that the two hypotheses, illustrated in Figure 1, imply very differently designed innovation processes. If Mach's hypothesis is correct, innovation processes would benefit

from having accidents intentionally induced. As we shall see, that is exactly what some artists do. How one would best design accident into scientific innovation processes is not clear, but figuring that out, if Mach is correct, should be a high priority for business innovators.

Proving a degree of association between accident and importance in invention and discovery is likely to remain difficult. Efforts to correlate the two scales are likely to be suggestive, not conclusive. The purpose of our intensity scale in this paper is to refine and make more precise notions of the role of intention and expectation as they interact with the processes of business innovation, and to apply the scale to the practices of a set of expert innovators. It's a tool to think with. From this point onward, we proceed on the assumption that accident is in some way important in arriving at novel and valuable outputs. We note practices of some innovators that seem to reflect a belief in this possibility. And we derive some implications of this that can impact business innovation.

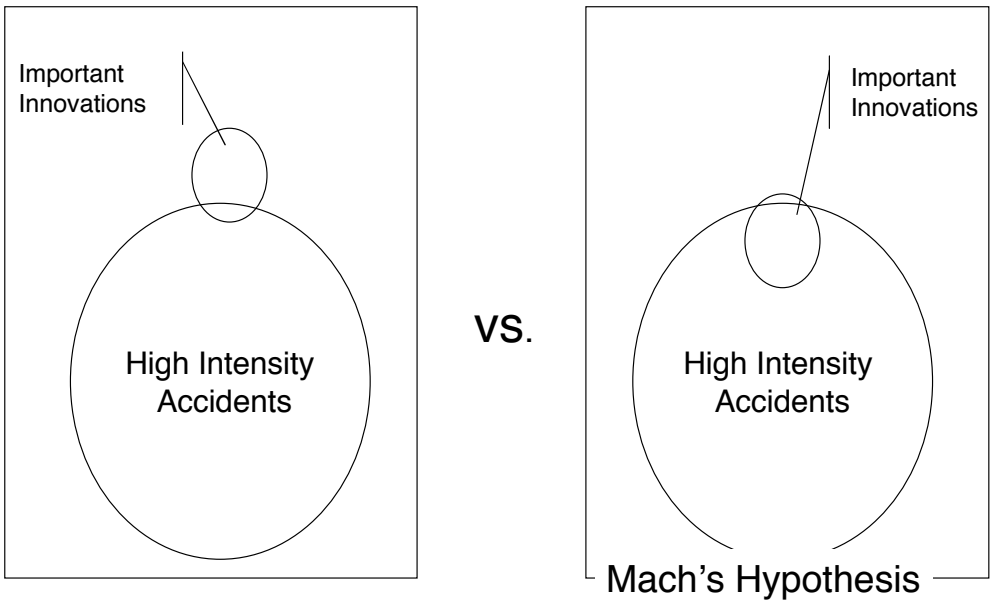

Figure 1

ACCIDENT IN ARTISTIC INNOVATION

Artists routinely accept the idea that accident plays a role in creating novel and valuable outcomes. As part of a larger study into the similarities and differences between innovation

processes in the arts and in business, we conducted in-depth, semi-structured interviews with six professional artists to probe their ideas about the role of accident in their work. In conducting the interviews, we used a standard template that we had developed from early stage field research in theatre and business (specifically, software development). In that earlier research, we asked similar questions of about a dozen people involved in collaborative theatre work; we got answers about the importance of accident consistent with what we report here; however, in this paper we focus on six interviews conducted more formally and analyzed in more detail. The interview template made sure that each interview covered similar ground, but allowed for variation in the order in which topics were addressed, the use of follow up questions, and length of time spent on particular topics. A coding template was used to capture qualitative data in certain categories of interest, one of which was the importance of accident in the subjects' work processes.

Interviews lasted between 45 minutes and two hours. This paper's first author conducted the interviews, and video taped them so that other researchers on our team could revisit and analyze them. To the extent possible, artists demonstrated the process they described. This was possible in half the interviews; for the other half we examined (and videotaped) the workspace while the artist described her or his work process. Seeing the work in context, or at least relating descriptions to actual work places, served as a check on our understanding of the process as described, and assured us that we were discussing actual rather than ideal processes.

We interviewed two metal sculptors (one of whom also made jewelry; the other also made prints), one glass blower, one potter (also a painter), one master print maker, and an oil painter (who was also an editorial cartoonist). Not all made a living from their artistic endeavors. Four did, one other was also an entrepreneur (a restaurant owner and real estate investor), and another also made jewelry to sell for income, an activity she regarded as creative but more commercial and less central to her passions than the conceptual sculptures for which she was best known. All, however, routinely sold their art and had achieved significant recognition in other ways (e.g., major art shows, national or international awards).

Thus all of these artists were "expert innovators" (a condition for inclusion in the study), although the value of their innovations was not necessarily expressed in economic terms.[3]

Findings from Artist Interviews

Analysis of the interviews shows that all six artists sought and depended upon novelty that arose during their work that was beyond their foresight as they began the work. The master printer explained how this happens by describing an example from his work with woodblock printing:

> I wasn't intending to do a piece of work. I just wanted to explore the mark making [using non-traditional tools]. All of a sudden I began to realize there is a landscape in there if I looked at it, used my imagination a bit more…There is an incidental line that ran through here [pointing]. So this is the beginning now. Now I can see landscape because of that division. And if you look very closely, at this incidental mark up here, there is the beginning of what could be a hill or a mountain. And the next piece would be this one here [revealing another print], which is the first in two colors. This is yellow and slight orange. And from that it developed into this one here [another print]. Now you begin to see the land area and a possible water area down here, even though this isn't a watercolor. Then that developed into these two here [two more prints]. I was able to bring out the sky and the blue, bring out the mountain area in this green here, and I printed two different greens in this area in the bottom here. And the landscape is beginning to form…I was very pleased with the results, because a lot of them were marks that were not intended to represent color in landscape.

Outcomes beyond the artist's original intentions are obviously important in this description of how he created this particular innovative product. The description became even more interesting as he generalized it, explaining how he routinely depends on emergent elements in his work, elements that are beyond his intention and foresight:

> It's like looking into the future, I suppose, but bringing that future, that vision into reality…is creating within the process…Letting the idea grow…The idea begins to grow within the printing process itself. It is always full of surprises, because looking at a plate does not tell you what's really there, only printing it can tell you. And when you print an etching, peeling back the paper on the

[3] Economic value is too variable a measure of artistic merit to use in our study. Some of the expert innovators in our study, although they all produced novel outputs valuable according to outside criteria, did not aspire to maximize economic value (i.e., money they could make from their art). Moreover, economic value is probably too narrow a measure of artistic expertise; a lot of art that's not appreciated in its time commands big money eventually. This is arguably true in business too; in the contexts in which innovations with great business value originally appear, they are often poorly monetized, and their value is often not widely recognized (think of Xerox PARC in the 1970s, the source of information technology innovations that are now likely worth hundreds of billions of US dollars in market capitalization – Xerox, however, famously monetized very little of this value; see Hiltzik, 1999).

> plate on the etching press is the first time you see it as your marks or your composition of color represented on paper. It can be disastrous. It can be absolutely delightful. Or you may suddenly realize that something has happened that you had not intended, that this is contributing to this process, and everything can change.

Other artists described a similarly emergent character in their processes. Metal sculptor #1 denied that the most valuable aspects of her work could be planned in advance, stating that it "all happens in the middle"; "I don't really know where I am going when I start," she insisted, "…and for me that's a good thing." Metal sculptor #2 made similar observations: "…it evolves on its own. The fish [sculpture] I built 12 years ago was very different than the fish [sculpture] I build now. I built seven of them this winter, in a row, and there was an evolution from the first one to the seventh one."

Often in our interviews, artists went further than merely pointing out the importance of unintended and surprising elements in their work, to warning that strong plans or intentions can prevent emergent outcomes. The master printer put it this way: "One thing that I do not do, and I encourage [other] artists not to do the same thing, is to have a finished drawing or finished color study to start working, lets say an etching, from; because really that piece of artwork, that event, has already happened, and I am in danger of merely copying that onto an etching plate." The glass blower said that his willingness to allow unexpected elements to emerge in his work signaled his growing maturity as an artist; while in early days he "forced" work into alignment with his intentions, he described how this had changed as he become a better artist: "[Now] a lot of the goblets that I make, you know, I just let them open up on their own..."

The desire to encounter novelty beyond intention and expectation, and the excitement that results from such experiences, was intimately connect to the artists' reasons for being artists. Metal sculptor #1 explained this most clearly:

> I think I would be bored silly if I knew where I was going when I started. I think the fun would be gone out of the process. What's the point of the process if you already know what your end is going to be? So the thrill of the creation for me is, comes through the process, getting to the end.

Others also remarked on this point. Metal sculptor #2:

> [When] you are in a production mode it gets predictable, that is the part where it stops being interesting. When I worked with clay and I was working with electric kilns and very predictable glazes, it got very boring quickly. When I worked with raku [a wood fired kiln that creates random effects with smoke and variable heat] and everything was a bit spontaneous and you never knew exactly what you were going to get, it was much more exciting…How much I am enjoying myself is related to the degree of the surprise…When it becomes regular and predictable, it's time to leave it and move on to something else.

And, the master printer: "I look for the surprise, for the alteration of the process that is slightly out of my control, thank goodness, and that keeps the whole things alive for me."

Frequently, artists used the word "accident." The oil painter, for example, explicitly described the role accidents played in his work:

> A lot of terrific accidents happen, yes, and those you want to keep. It might be a texture. It might be a color or texture hitting the surface of the canvas that you want to keep. That's totally a random accident. If it's a great accident like that, that shows depth or texture, you want to keep that.

The potter offered thoughts on the subject that were even more to the point:

> Things happen with clay…unexpected things—. You *can* control clay, precisely. But often things happen. And if they happen accidentally—and I was often looking for the accidental things…I love accidental, things that aren't too perfect. Too perfect gets boring, often.

The glass blower, in the segment of his interview in which he discussed the advantages of letting pieces "open up on their own" also clearly suggested that outcomes aligned precisely with his intentions were less interesting than those that contained some element of the unintentional and unexpected.

We found that several of the artists tried to *induce* accidents in their work. The master printer described one such attempt that he argued was a turning point in his maturation as an artist:

> The copper [etching] plates that were provided to us were highly polished. It used to scare the heck out of me. Then I decided, "This is it; I am going to declare war on this." I took my plate in to the car park, face down and kicked it around for a half an hour. I came back, prepared the plate, printed it, and thought "right, this plate is on its way."…Even the random can be brought into some kind of order. So this sort of reaction or working the plates had some very interesting results.

As he did with other examples, the master printer enlarged upon this example to suggest a more general principle:

> Let's say that we drop a plate and it picks up a scratch. Now we can curse the whole thing, and say what a stupid thing to do, drop the plate. On the other hand though, has it left a mark that is a part of the history of making the plate? Sometimes those incidental things, odd scratches in the plate or little areas where perhaps the acid gets through a resist, where we never intended it to…it can be a gift or a disaster. It depends on how you want to look at it.

Similarly, the oil painter described how he sometimes "started with my elbow dipped into the paint" to introduce a random element. The potter was most extreme in his efforts to introduce an element of the accidental into his work:

> These cases, like this one and this one, and that one down there [referring to three different pots each with sharp protrusions on their mouths], I'll hit them with a piece of 1 by 2, and snap it at its rim, anytime, a half an hour or so after I make it. In this case that whole piece came out with it. "Ooh, that's good," I thought. "That's fine." You can see where the stick hit, but I snapped it off quickly, just barely flicked it at it, and pulled it out, and ooh, that's quite wonderful. When I take this hunk of wood and swat it at a pot—not a lot of control. I mean, sometimes, the whole thing comes off. You end up with a stick and a slab of clay hooked on. But that—[he indicates the region of protrusion on a particular pot]—that is just wonderful in there.

The cost of accidents that do not prove valuable are often of concern to people in business. In business, people tend to call such efforts "failures." In probing this idea with our interview subjects, however, we found again and again a deep reluctance to label unproductive events as failures, and an emphasis on the importance of the novelty that was thereby accessed. Metal sculptor #2, responding to an interviewer question about the cost of trying something that "failed" had this to say:

> Yeah, but you may have gained an insight, so the time was spent on that instead of having a final object…So time might have been well spent even though there was nothing to show for it, other than experience.

The master printer remarked in the same vein:

> One has to accept the fact that paper is going to be used up and could end up in the garbage bin, but that is a stepping stone towards a finer piece of work…I suppose there is a parallel in painting where…artists rework [by] painting over [already painted areas on the canvas]. Well think about the cost of the paint that is underneath, that is no longer part of the painting. But it was a necessary part, or has become a vehicle towards the final painting. Because to have an artist say that color is not correct there, then you have to put it down and judge it in relationship to other colors, or on the form, then you know which color to put on top. So is that wasted really?

The overall picture that emerges from our interviews with artistic innovators reveals openness to accident, reliance on it, and even attempts to introduce it. These artists saw an understanding of accident in their work as a sign of increasing artistic maturity.

Comparison with Innovation Process in Business and Science

The degree of openness to accident exhibited by these artists contrasts with many business prescriptions for innovation processes. New drug development provides an illustrative example. Critiques of what has been called "industrialized drug research" (e.g, Landers, 2004; Sherman and Ross, 2003), research which uses computer automation to test promising substances at faster than human speeds, suggest that the approach often fails because it assumes that important new drugs will be discovered in predictable ways (i.e., within the search space programmed into the automated system). Detractors note that blockbuster drug discoveries often happen in unexpected ways, as in the example cited earlier of Schering-Plough scientists stumbling onto a new way to reduce cholesterol. These critics point to a recent tendency of the pharmaceuticals industry, the so-called "productivity problem" in today's drug research (Tsao, 2004): Companies produce many better drugs, but few real blockbusters (really important inventions, in Mach's terms), in spite of billions of dollars invested in automation.

Business firms and management researchers often portray innovation processes, such as those used in product development, in ways that imply "separation, logical order, planning and product-process symmetry" (Thornquist, 2005; Gudenrud, 1998). Some have suggested that companies using sequential process models, with methodical early stages aimed at planning and analysis, will be more successful (Cooper and Kleinschmidt, 1986, 1987; Trueman, 1999). Such models typically emphasize "generic, step-by-step and systematic process, involving distinct stages, from identification of needs through to concept refinement and final production" (Thornquist, 2005). The descriptions convey a sense of business innovation as a process of "harnessing" creativity, directing it to line up with intention. Such descriptions marginalize any notion of accident, and repudiate any idea of induced accident.

Depictions of orderly and predictable scientific innovation have also attracted distinguished and harsh critics. Consider, for example, the comments of Nobel Laureate Sir Alan L. Hodgkin: "I believe that the record of published papers conveys an impression of directedness and planning which does not at all coincide with the actual sequence of events" (1977). Another scientist of note, Sir Peter B. Medawar, has asked, "Is the scientific paper, which embodies a fictional inductive method, at root fraudulent?" (1964). And the eminent sociologist of science, Robert K. Merton, has observed, "the etiquette governing the writing of scientific (or scholarly) papers requires them to be works of vast expurgation…" All these comments came in the context of arguments that representations of scientific innovation are far more orderly and logical than the process itself. Facts discovered by accident or inventions arrived at by chance gain deliberate and logical processes in memory. Often the institutions that govern the practice of innovation provide incentives to revisionism. For example, it might be impossible to publish a scientific paper that truthfully depicts the "methodology" involved in creating a novel and valuable outcome, and scientists need to publish findings to get funding for the next project.

There may be perfectly legitimate reasons to revise stories about accident in discovery and invention, or to de-emphasize accident as a way of creating new and valuable outcomes. For example, in setting out an orderly description of a scientific experiment, a researcher might legitimately aspire to describe a process that is most likely to result in successful *replication* of the experiment. The way the experiment was carried out the first time is rarely the way the product will be made after it's discovered. Another reason prescriptions in certain scientific settings might not naturally emphasize the role of accident: the opposite problem, of limiting uncontrolled variation, might be so big an issue in arriving at understanding of something that adding more variation would be unthinkable. But these are special cases that do not explain fully the business inclination toward taming what is "savage" (Thornquist, 2005) in innovative work.

INCORPORATING ACCIDENT INTO BUSINESS INNOVATION

Campbell (1960) proposes a model of creative process inspired by Darwinian evolution that he summarizes as "blind variation and selective retention." Blind variation produces novelty, selective retention secures value. In this formulation, innovation shifts away from controlled, methodical process, towards fruitful accidents, towards recognizing value in surprising results, and towards seizing and building upon retained outcomes. As Mach (1896) put it: "accident alone is [not] sufficient to produce an invention." Rather, the inventor must "take note of the new fact… grasp its advantageous feature…and turn that feature to account in the realization of his purpose." Preparation for innovation then involves skills intended to produce useful accidents, and to recognize and build upon them when they occur.

This accident-prone view of innovation suggests a process:

1. Watch for accidents, examine them for value;
2. If valuable accidents don't happen often enough, generate some;
3. Seize upon useful accidents, capture their valuable features;
4. Build on seized accidents to create more value and the potential for future useful accidents.

This requires you to maintain a favorable predisposition toward events that are beyond intention and foresight, which predisposition does not come naturally to many people trained in management. In business, avoiding unplanned variation may be a hard-won skill, a deeply embedded, because effortfully learned, reflex. The need to avoid unplanned variation is, in fact, a major part of the rationale for the traditional sequential form of design methods. Early planning and analysis phases, considered by many as the key to successful process, aim to foreclose the possibility of later variations. Exhortations against "scope creep" in project management express this sentiment against variation in customer requirements (which may themselves be a result of variation in the business environment):

> Scope creep is the expression used by project managers under pressure to deliver in excess of what was originally agreed...Scope of the original plan can start to move—and continue to move. If the project manager is not alert

> ... the requirements will constantly change...the project spends years on delivering nothing… continually reviewing and altering direction.[4]

Project managers are encouraged to avoid exactly what delights artful innovators: constant review; changing direction in unexpected ways toward unpredictable outcomes.

An accident-prone innovation process may be uncomfortable for business managers for other reasons. *Blind* variation implies real breakage or malfunction, movement outside of intention and *ex ante* logic—not search strategies that vary in pre-specified and *ex ante* justifiable ways. It suggests that a blockbuster drug, say, might appear in a screw up for which there was no warning instead of in a carefully planned process. If it did, what hope can we have for the next one?

Lewis Thomas (1983), a medical doctor writing about the progress of research in neuroscience, suggests a connection between genuine error and human progress by contrasting human mental function with computer processing:

> Computers are good at seeing patterns, better than we are. They can connect things that seem unrelated to each other, scanning the night sky or the stained blotches of 50,000 proteins on an electrophoretic gel or the numbers generated by all the world's stock markets, and find relationships that matter. We do something like this with our brains, but we do it differently; we get things wrong. We use information...for leading to thoughts that really are unrelated, unconnected, patternless, and sometimes therefore quite new. If the human brain had not possessed this special gift, we would still be sharpening bones, muttering to ourselves, unable to make up a poem or even whistle (pp. 89-90).

The specific nature of the breakage (i.e., the search strategy) involved in this kind of innovation cannot be designed, although a process that permits and even induces true breakage can be. The potter can plan to whack a drying pot with a stick, but he cannot pre-program the consequences. This proposed relationship, between chance and human progress, suggests another hypothesis, shown in Figure 2. True breakage is usually less efficient than planned search, but it may result in bigger payoffs.

[4] http://www.yourwindow.to/information-security/gl_scopecreep.htm

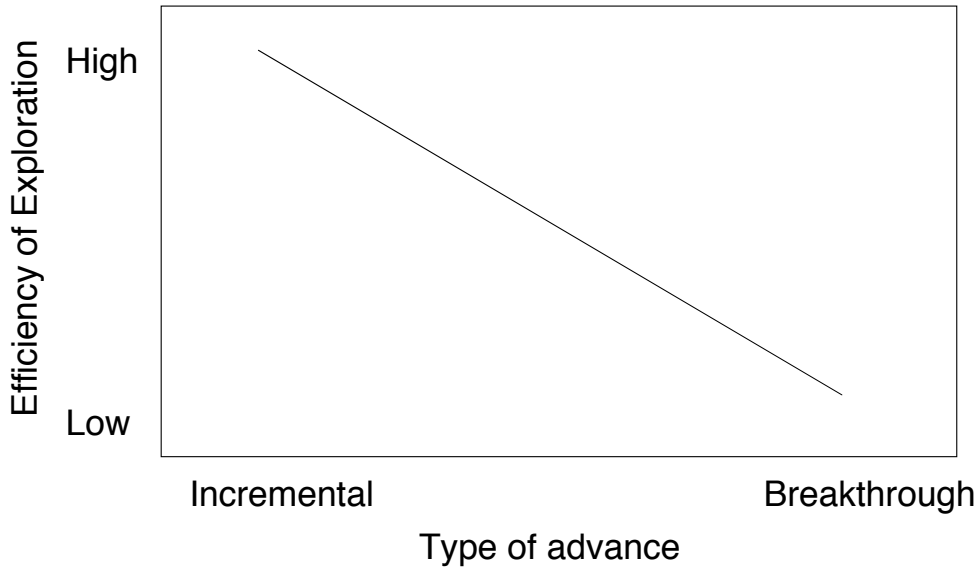

Figure 2

There are many possible sources of variation that innovation processes can tap into, some of which may also be uncomfortable for control-oriented business managers. These include:

- Induced accidents;
- Induced playfulness that combines unlikely components in unpredictable ways, a practice that Einstein used and referred to as "combinatorial play" (1949);
- "Productive forgetting" (Simon, 1966): putting work aside so that it can "incubate." The cognitive mechanism proposed by Simon involved forgetting the some of the logical steps that led to a particular conclusion, thereby rendering pre-determined memory structures unstable; reconstructing them later would be more likely to generate novelty, rather than mere recall of the old memory structures;
- Deliberately maintaining an "almost unbearable" tension (Kuhn, 1963) between established logic and unlikely possibilities; musician Paul Robertson (2005) has described a similar process that he advocates in the arts, which he describes as "suspending yourself in paradox."
- Work with others who are different from yourself; collaboration among individuals of diverse background and expertise almost always forces people to encounter unfamiliar, unexpected ideas; although many in business may experience this kind of difference as inefficient, difficult, or even chaotic, the need to produce blind variation on the way to novelty suggests that we should cultivate this kind of "creative abrasion" (Leonard and Swap, 1999).
- Increased interdependence (reduced modularity) in work components; this runs counter to most business reflexes, but activities with a significant degree of

interdependence are more likely to product unexpected and non-linear effects that lead to real novelty (Austin and Devin, 2003).

- Psychopathology or neurological problem; Simonton (1999) examines the "mad genius" hypothesis, which asserts a connection between pathology and innovation, and comes away concluding that a relationship cannot be discounted. As Simonton also points out, great achievers in history suffer childhood trauma of the sort that might induce serious mental dysfunction (such as loss of a parent) much moreoften than the population at large. So do prisoners and delinquents, which suggests that trauma and resulting pathology may cut both ways; it may be beneficial to involve in an innovation process some degree of dysfunction that produces novelty, but too much may be counterproductive.

GETTING OUTSIDE THE "CONE OF EXPECTATION"

As shown in Figure 3, when innovators induce accident within their process or otherwise seek sources of blind variation, it may be a way of getting outside their own "cone of expectations." When a person acts intentionally, he or she creates the possibility of events that can be expected given the available predictive chains of logic. But, as the artists we interviewed made clear, these expectations can be a barrier to creation of novelty. The best innovation processes, in the arts or business, may generate events outside the innovator's zone of expectation; even if most of these events do not get retained, eventually there is an outcome—like the surprising cholesterol experiment at Schering-Plough—that suggests a new chain of logic, a way of expanding or adjusting the current cone of expectation.

The urge to get outside the cone of expectation may also suggest a partial explanation for what Amabile (1996) has called the "intrinsic motivation principle of creativity." Amabile argues that a preponderance of empirical evidence warrants the conclusion that "the intrinsically motivated state is conducive to creativity, whereas the extrinsically motivated state is detrimental." When it comes to creative tasks, extrinsic motivators, such as commissions or other forms of payment, seem to have an adverse effect on the creativity (as reliably judged by independent observers)—novelty plus usefulness—of outcomes. Many innovators express intolerance or discomfort with extrinsic motivators, as if they interfere with the process of innovation. Dostoevsky's complaint, in a letter, on this subject is typical: "I believe you have never written to order, by the yard, and have never experienced that

hellish torture" (Allen, 1948). Extrinsic motivators may be hellish torture for those seeking real novelty because they are necessarily based on existing logics and predictive frameworks. As such, innovators may experience them as part of the infrastructure that threatens to keep outcomes within cones of expectation (theirs or those of their patrons or supervisors).

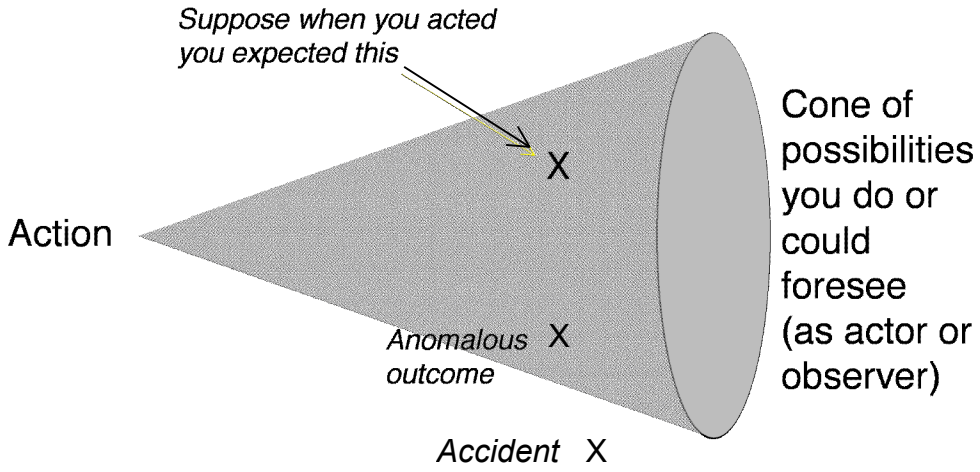

Figure 3

The fact that novel and valuable events suggest their own logic also goes a long way toward explaining why efforts to make innovation orderly and predictable cannot succeed. Accidents that suggest their own logic each achieve value in a unique way. The innovator who draws on accident in her or his work understands intuitively that deductive use of current logic will be of limited help in arriving at new logic. In a sense, the new logic implies that new events are draws from different statistical populations; the populations defined by old logics can't predict "new "events.

To rely on accident to generate blind variation does not necessarily imply lack of control of innovation processes, nor lack of reliability. An outcome that is outside the cone of expectation can still fulfill the "requirements" associated with a business situation, though perhaps in a novel and exciting (maybe disturbing at first) way. An innovative outcome can still be consistent with the "requirements document" or comply with GAAP. Evidence from arts practice demonstrates also that innovative products can be produced on deadline. Few

business deadlines are as inflexible as opening night for a theater company or an orchestra. Yet good theatres and orchestras consistently produce innovative products within these deadlines.

CONCLUSION

If we return to the notion of accident intensity we observe that low intensity accidents occur in primarily deductive settings and are of limited help in getting outside of the cone of expectation; Kekule's dream was an odd step in his reasoning, but it was a natural extension of his intentions and, hence, his expectations. On the other hand, Level 4 accidents may be too weird to serve as a practical basis for deliberate innovation; the Kellogg brothers' invention of cornflakes had no innovative intention. Level 2 and 3 accidents seem about right for business innovation processes. Accidents at this level have the potential to create real novelty, but they can also be aimed to some degree.

Processes that rely on accident require people who cultivate a special sensitivity to possibilities they have not foreseen. For example, theatre artists have invented tactics to free themselves from the controlling influences of presumptions and predispositions, to make themselves more able to act "in present time," as the specific current circumstances demand (Austin and Devin, 2003). Certain organizational activities, such as the simulation training that supported the Apollo moon missions, appear to fulfill a similar function. In some ways, the attitude required by an accident-prone innovation process is consistent with the Japanese management "kaizen" improvement philosophy, which advocates openness to unpredictable opportunities. A kaizen-like watchfulness aimed less narrowly at process improvement, and applied more generally to the process of innovation, could be a powerful tool if coupled with a method that generates blind variation.

If we take seriously Campbell's Random Variation and Selective Retention model as a basis for a designed innovation process, we need both an engine for generating variation and a capability for recognizing and retaining value when it appears. Our processes for innovating

must allow for both. The earlier described criticisms of industrialized drug research are particularly interesting in this light. Industrialized drug research, which aspires to test compounds very quickly and cheaply, is a partial-step in the right direction because automating experiments makes them happen faster and the faster we can do experiments (Thomke, 2003), the more likely we are to experience accidents. The problem, as critics have pointed out, is that in a very fast, automated testing system, the human mind, however well prepared, does not have a chance to recognize accidental value; it goes by too quickly. This observation suggests another design tradeoff for innovation systems that rely on valuable accidents. Although turning up the rate of experimentation, the number of iterations per unit of time, speeds up the production of accidents, it also, beyond a point, makes it harder to notice important accidents. The optimal rate of experimentation may, therefore, be at a point of intersection between two curves shown in Figure 4.

If we think back to the interplay between accident and experiment in the story that began this paper, about Daguerre's process of invention, what this means is that the process must allow for this interplay. Some hold out that hope that, by arriving at sufficiently perceptive machines and software, we might also produce a capability within a fast, automated process to make decisions about next steps in reaction to unexpected outcomes. But that will depend on the machine's capacity to see beyond its "expectations." How easily and completely that will be achieved time will tell.

As we have noted, dealing with this an other issues in the design of an accident-prone innovation process, and going beyond such issues to a more sophisticated discussion of the process of innovation, requires getting past your deep habits of planning-intensive and variation-avoiding traditional business practice. In our field research in a theatre company, we came across the following expression of this tension by a staff member:

> [Art] needs to provide the experience of making the impossible possible. Making the impossible possible, even in the arena of make-believe or pretend, does something to your brain. It allows you to envision—not plan—that's completely different. Planning is an activity that involves

> weighing pros and cons, taking into consideration available resources, and coming up with a strategy to achieve your goals. The things you are able to plan are those things you see as being possible. Impossibilities never make it to the planning stage. Whereas envisioning involves faith in a maybe and a belief in the chance that the maybe can become a yes.[5]

A statement by William Jevons (1877), a chronicler of the practice of science, seems startlingly similar in its message:

> [T]he erroneous guesses must be many times as numerous as those that prove well founded. The weakest analogies, the most whimsical notions, the most apparently absurd theories, may pass through the teeming brain, and no record remain of more than the hundredth part…The truest theories involve suppositions which are inconceivable…"

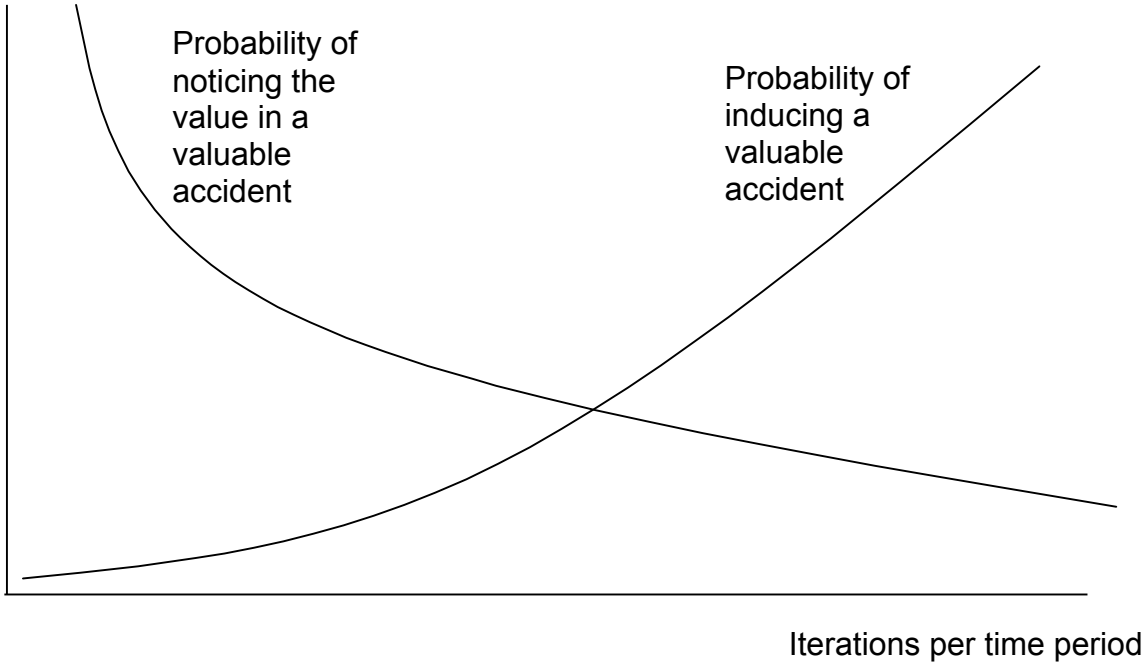

Figure 4

[5] Abigail Adams, artistic director of the People's Light and Theatre Company quoting a student in one of her classes, "Aisha."

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