The Psychological Record (2021) 71:517–523
https://doi.org/10.1007/s40732-020-00410-5

THEORETICAL ARTICLE

The Creative Tripod: The Stitching and the Unstitching Revisited

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Abstract

There are no undebated definitions of “creativity,” and any definition will reflect how this rich topic is treated. Nearly 20 years ago I discussed how behavior analysis might contribute—or not—to an understanding of creativity. I revisit this topic, expanding on some issues and reconsidering others. As before, my focus is on scientific and mathematical accomplishments, which, though tied closely to Weisberg’s placement of creative achievements in the domains of problem posing and problem solving, places emphasis on the extraordinary and productive giftedness of certain individuals. From the massive empirical, theoretical, and historical literature at least three essential and dynamically interlocking dimensions of their creative achievements emerge: talent, expertise, and motivation. I emphasize “interlocking” because the productive expression of each of these elements depends on the others. The role of behavior analysis in these elements is modest at best. It has nothing to say about talent—and even in some cases might deny its role altogether. As for expertise, with some notable exceptions, behavior analysis has had little to say about the acquisition of truly complex performances; this has been left to other fields. As for motivation, one must go well beyond naïve “pleasure and pain” accounts to more elusive, yet more powerful behavior–consequence relations. Many challenges to understanding remain for all behavioral scientists.

Keywords creativity · talent · expertise · motivation · genius · emergenesis

> A line will take us hours maybe;
> Yet if does not seem a moment’s thought
> Our stitching and unstitching has been naught.
> from “Adam’s Curse,” W. B. Yeats, Finneran (1996, p. 80).

In May of 2001 at the Association for Behavior Analysis conference in New Orleans, I gave a Presidential Address entitled “The Stitching and the Unstitching: What Can Behavior Analysis Say about Creativity,” later published in *The Behavior Analyst* (Marr, 2003). A quick summary of that article is: traditional critics of behaviorism and behavior analysis have emphasized that these approaches cannot deal with creative achievements in the arts or sciences, or even in ordinary speech. I explored several lines of research and conceptual issues from different sources, in an effort to refute this claim. My emphasis was on scientific and mathematical creativity, both of which fit well into Weisberg’s approach to creativity as significant problem finding and problem solving (e.g., Weisberg, 1993, 2006, 2018). The topics I considered included the role of special practice and manipulation, the conditions for development of automaticity, the interplay of contingency-controlled and rule-guided behavior, modeling, variation and selection, abstraction, intuition, the blending of repertoires, and emergent behavior. I also considered certain limitations of a behavioral account, in particular as they related to the role of individual differences and the interplay among talent, expertise, and motivation. My purpose in revisiting the topic of creativity is to discuss this interplay largely by presenting compelling examples and reflecting on the challenges of understanding them.

Before pursuing this interplay, I offer a few general remarks on creativity itself: typing “creativity” into Amazon books yields more than 50,000 entries. This is unsurprising, but considering only the literature that might be considered “scientific” still brings up a huge list of sources. However daunting, any serious consideration of the topic requires some familiarity with that literature just to get started. Topics include empirical studies of creativity, psychometric assessment of high-achieving individuals, historical and bibliographic

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studies of creative scientists and artists, studies of the acquisition and exercise of expertise, studies of prodigies, savants, and other gifted individuals, and, of course, the nature–nurture controversies, which often become quite heated (e.g., Kaufman & Sternberg, 2019; Plucker, 2017; Runco, 2014; Simonton, 2014; Sternberg & Davidson, 2005; Sternberg & Kaufman, 2018; Weisberg, 2006). As for "creativity" itself, controversy begins with seeking a workable definition. There is an enormous range of current formulations (e.g., Kaufman & Glăveanu, 2019), but I will reduce them to a small set. Some, like Weisberg (2006), primarily emphasize the intentional production of a novel product; others, like Csikszentmihalyi (2013, 2014) emphasize the social/cultural/critical valuing of such a product as essential in defining it as a creative achievement. Still others, like Sternberg (e.g., 1999), explore what contributes to value in a creative product. I cannot discuss all the issues and topics that are basic to any serious treatment of creativity; nonetheless, when relevant, I will refer to certain key sources.

From the outset, I should be clear that what follows is not reflective of the broad range of what might be deemed creative, or even some of those accomplishments of major significance, as ably argued, for example, by Weisberg (e.g., 2006). Weisberg discusses such achievements as Watson and Crick's discovery of the structure of DNA, the Wright brothers' development of powered flight, Picasso's *Guernica*, and other examples, to illustrate the role of problem solving in creative products. As such, problem solving is reflective of what Weisberg deems "ordinary thinking," and, according to him, in general, creative accomplishments are not the products of "extraordinary thinking." The implication is that to the extent we understand the processes of ordinary problem solving, and to some extent we do, we can understand how certain creative products were achieved. Although Weisberg's examples, including the essentials of history, context, and even happenstance, may compellingly illustrate this, I am interested in cases where the conditions, thinking and otherwise, are "extraordinary," and for which we have far less understanding, as I shall try to relate. These conditions involve three essential and interlocking aspects: talent, expertise, and motivation.

I have selected a domain that illustrates relatively clear cases of creativity with minimal controversy, to allow for some judgment of the necessary—but certainly not sufficient—conditions for creative achievements to be recognized by anyone who knows something of the domain—and even many who don't. My examples come from outstanding accomplishments in mathematics and physics over the last century or so. Although there are many names to choose from, all the cases with which I am familiar show similar patterns.

I recognize the artificiality of treating my three essential and interlocking elements—talent, expertise, and motivation—in separate sections, given that none of them functions in isolation. Nevertheless, I begin with talent, one aspect that clearly characterizes the accomplishments of the examples I present. You will also see how the other two, expertise and motivation, are enfolded into the examples. I should also emphasize that all these elements are identified by *behaviors*.

Talent

I am using "talent" in the sense of a demonstrable display of behaviors considered by others as remarkable in both their quality and their early age of appearance (e.g., Sternberg & Davidson, 2005). Another term commonly used is "gifted," and I will not argue over possible differences between this term and talent and use them interchangeably. Of course, terminology and definitions vary considerably and, however used, talent is likely the most disputable of my three, largely due to its central place in the nature–nurture battles. Most researchers in creativity and expertise acknowledge the role of talent in some way and take it to be, at least in part, a reflection of complex "emergenic" and epigenetic processes that are little understood, but for which there is compelling evidence (e.g., Lykken, 1982, 1998; Lykken, McGue, Tellegen, & Bouchard, 1992; Simonton, 1999, 2001, 2005). Though there are various cases and complications, the essence of extreme giftedness reflects both the *multiplicative* expression of polygenetic factors underlying particular traits and complex developmental processes that may control genetic expression. Such dynamics display highly skewed distributions—these gifted individuals are not simply far out on some normal distribution continuum; rather, their particular configurations of factors yield unique, asymmetric distributions. Moreover, as opposed to some additive contribution, the multiplicative aspects of gene expression mean that if one factor is missing, then the processes leading to giftedness fail.

However mysterious, I, for one, believe that the evidence supporting the concept of giftedness is overwhelming, including my own experiences with those undoubtedly gifted.[1] But others, notably Ericsson (e.g., 2014), appear to discount the concept altogether. For example, Ericsson finds little scientific evidence in his studies for the essential role of some particular hereditary configuration to accomplishment, however remarkable in quality or early appearance. (But see Macnamara et al., 2018.) He has been labeled a "radical environmentalist," a view often and unfairly attributed to behavior analysts, though, in truth, I have known some in our field who hold such a view. Without question, assuming that the role of something called talent exists, its flowering requires a set of

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[1] In the late 1990s and early 2000s I was a southeastern regional judge in the national Siemens-Westinghouse Science Talent Search (sadly, now defunct). I was privileged to interview at depth many remarkably talented and creative high school students.

supporting and amplifying conditions in the social/cultural milieu: acknowledgement and encouragement by family and colleagues, proper tutoring, and a host of other conditions and contingencies, all of which we may call "the environment."

As for evidence, there are many sources, starting with Julian Stanley's (1996) groundbreaking studies of the mathematically gifted, and these have been followed up extensively by David Lubinski and his colleagues (e.g., Kell & Lubinski, 2014). In addition, there are numerous psychometric studies of scientific talent and eminence, including Eysenck (1995) on genius, the previously cited studies on emergenesis and epigenetics, and many other papers on giftedness (e.g., Morelock, 1996; Kaufman, 2013; Simonton, 2014; Sternberg & Davidson, 2005).

Below, I will provide a few examples that illustrate what I consider "talent," the expression of which goes far beyond any conceivable nurturing environment, however necessary. Karolyi and Winner (2005), in their chapter on "Extreme Giftedness," characterize such children as "(1) precocious in their domain of ability, (2) they are passionate about and have a rage to master that domain, (3) they think, learn, and solve problems in ways that are qualitatively different from typical children, and (4) they are aware of being different from others" (p. 378). The expression of these features continues for those who go on to major accomplishments in their respective fields, as amply illustrated by the following examples.[2]

Julian Swinger, a Nobel Prize-winning physicist, he published a paper in the *Physical Review* at 17, but wrote his first paper on quantum electrodynamics at 16 (Schweber, 1994).

Freeman Dyson at 14 spent his Christmas vacation working through Piaggio's *Differential Equations*, solving all of its more than 700 problems (Dyson, 1979). To get some idea of Dyson's accomplishments, such a book (though modernized in methods and presentation) might be used today for a late sophomore or early junior-level course for physics or engineering students who would typically be 20 or more years old and would have already taken nearly 2 years of calculus. Moreover, they would not be required to solve *all* the problems, only a small sample—many of the more difficult problems would require considerable ingenuity to solve.

Richard Feynman, as a 15-year-old high-school student, taught himself mathematics by working through standard texts in trigonometry, the calculus, and well-beyond, keeping elaborate notebooks of carefully worked problems. Rather than simply looking up or copying table values and functions, he calculated logarithmic and trigonometric values directly and derived tables of integrals for himself (Mehra, 1994).

Srinivasa Ramanujan, arguably the 20th century's greatest mathematician (and certainly the most mysterious), was already on his way at age 16, having spent virtually all his waking hours doing mathematics with very little tutoring. As a 16-year-old, he worked through Carr's *A Synopsis of Elementary Results in Pure and Applied Mathematics*, a compendium of some 5,000 formulas, theorems, etc., all presented largely without any indications of proof. Ramanujan supplied the proofs (Kanigel, 1991).

Terry Tao, a 2006 Fields medalist (the "Nobel Prize" in mathematics) and MacArthur ("genius grant") prize winner, scored 760 on the SAT math test when 8 years old and earned his PhD at 20. He has made deep contributions to many areas of mathematics (Kell & Lubinski, 2014; Tao, 2020). Another Fields medal winner, Timothy Gowers, had this to say about Tao:

> Tao's mathematical knowledge has an extraordinary combination of breadth and depth: he can write confidently and authoritatively on topics as diverse as partial differential equations, analytic number theory, the geometry of 3-manifolds, nonstandard analysis, group theory, model theory, quantum mechanics, probability, ergodic theory, combinatorics, harmonic analysis, image processing, functional analysis, and many others. Some of these are areas to which he has made fundamental contributions. Others are areas that he appears to understand at the deep intuitive level of an expert despite officially not working in those areas. How he does all this, as well as writing papers and books at a prodigious rate, is a complete mystery. It has been said that David Hilbert was the last person to know all of mathematics, but it is not easy to find gaps in Tao's knowledge, and if you do then you may well find that the gaps have been filled a year later. (Tao, n.d.)

At age 16, *Marc Kac*, an eminent mathematician known mostly for his work in probability theory, took on the problem of solving the cubic equation. Though this problem had been solved by Cardano in the 16th century, the proof was unknown to Kac. After what he describes as a "virus of obsession"—working all day from morning until night filling reams of paper, he succeeded in formulating an original proof. Kac (1987) is also known for a famous quote:

> In science as well as other fields of human endeavor there are two kinds of genius: the "ordinary" and the "magicians." An ordinary genius is a fellow that you and I would be just as good as, if we were only many

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[2] One reviewer rightly pointed to the lack of women in my list. Of course there are, and have been, many women mathematicians and scientists of historic accomplishment, such as Hypatia, Sophie Germain, Ada Byron Lovelace, Sofia Kovalevskaya, Emmy Noether, Marie and Irène Curie, Lise Meitner, Katherine Johnson, and Maryam Mirzakhani, to name but a few. In my attempt to document extraordinary abilities in mathematics at very early ages, I could find little relevant biographical detail for these women. In some cases, they may have shown giftedness at an early age, but in other more artistic and literary domains (e.g., music, languages, writing). It is sad that many women were discouraged, if not outright banned, from mathematical and scientific pursuits, and came to achieve these later than they might otherwise have. Given such barriers, the achievements are all the more remarkable.

> times better. There is no mystery as to how his mind works. Once we understand what he has done, we feel certain that we, too, could have done it. It is different with the magicians. They are, to use mathematical jargon, in the orthogonal component of where we are and the working of their minds is for all intents and purposes incomprehensible. Even after we understand what they have done, the process by which they have done it is completely dark. (p. xxv)

Ramanujan, Feynman, Einstein, Tao, and a very few others were clearly magicians. And speaking of magicians: Perhaps the most remarkable of all, *John von Neumann*, who many consider a talent far beyond genius, some speaking of him as one at a higher stage of human development, further evolved than the rest of us—"a demigod who had made a detailed study of humans and could imitate them perfectly" (Heims, 1980, p. 26) is but one description. By the age of 6 he could divide or multiply two 8-digit numbers in his head and speak ancient Greek. Eugene Wigner, himself a Nobel laureate in physics, described his boyhood friend: "One had the impression of a perfect instrument whose gears were machined to mesh accurately to a thousandth of an inch" (Heims, 1980, p. 26). At their first meeting, when von Neumann was 15, the mathematician Szegö was so astounded by the boy's mathematical talent that he was moved to tears. His memory was prodigious, faultless, and enduring. Von Neumann's contributions in pure and applied mathematics included set theory, quantum mechanics, game theory, economics, computing, atomic weapons design, and many others. The range and significance of these creative achievements remain without peer, and are likely never to be equaled by any individual.

These kinds of examples can be greatly expanded, but all give hints of some of the essential factors we see in great accomplishments in mathematics and physics. They clearly illustrate the three major features of talent, expertise, and, in Kac's words, the "virus of obsession" in mastering a domain.

Expertise

As the above examples illustrate, significant accomplishments in any domain require the acquisition and exercise of extensive and complex repertoires that define what it means to be an expert (e.g., Ericsson, Hoffman, Kozbelt, & Williams, 2018; Hambrick, Campitelli, & Macnamara, 2018). Ericsson has been a major figure in his emphasis on intensive, relentless, obsessive, disciplined, devoted, and deliberate practice over many cumulative hours (typically 10,000—a variation of Chase and Simon's 10-year rule (Chase & Simon, 1973; see also Hayes, 1989) to achieve true expertise and major creative achievements. Such practice requires ever-increasing challenges to current levels of performance, not merely practicing what one can already do. Although one might cavil about the numbers here, especially in a field like mathematics, there is no debating that for those considered the greatest in the field, infection by the "virus of obsession" from an early age in doing mathematics is virtually universal, as my above examples illustrate (but see note 2).

There is the fundamental question of just how practice of the sort described by Ericsson works to achieve its ends. With some exceptions,[3] behavior analysts have shown little interest in the acquisition of complex skills of the sort illustrated in my discussion of talent, though I have discussed some potential contributions from behavior analysis in my earlier article and elsewhere (Marr, 2003, 2015; see also Winston & Baker, 1985). No doubt, processes such as contingency adduction, resurgence, relational framing, multiple exemplar training, complex and dynamic interactions between contingency-controlled and rule-guided behavior, behavioral variation in conjunction with selection, fluency-building, repertoire melding, and other less-understood mechanisms play important roles in the acquisition and expression of the huge repertoires attained from proper practice. Here is what I said in 2003:

> . . . I've indicated how basic behavioral processes of response-differentiation and stimulus control can result in complex stochastic and dynamic webs of associative links that may, in turn, engender novel behavior. One can think of a spider web where a slight tug at any one point may exert variations in effects at many distant points. This dynamical web is continually modified and extended through intensive, long-term interaction with a knowledge domain providing not simply an enormous repertoire of knowledge and skills, but automaticity at least to the level of elaborate relational, rule, and heuristic-based performances. These performances act functionally as if directly controlled by the contingencies related to the problem at hand. Given these conditions, a person's ability to manipulate the domain to generate problems as well as their solutions will to the uninitiated appear as astoundingly magical. Arthur C. Clarke once said that any sufficiently advanced technology would be indistinguishable from magic. (p. 25)

Of immense importance is that from this vast repertoire emerges *intuition*. (e.g., Marr, 2003, 2015) As I pointed out in my earlier article, "Even the creator may not appreciate what such a history may engender. The literature on creativity is replete with autobiographical descriptions of creative acts

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[3] Many behavior analysts would immediately cite Skinner's *Verbal Behavior* (1957) as a major exception; indeed, verbal behavior is the most complex behavior we know about. But as important as this work is (anyone interested in creativity should review Part IV), there is relatively little detailed treatment of *acquisition*.

that seem startling to the creator, as well as others, because the sources are lost to them in a sea of experience" (Marr, 2003, p. 24).

Motivation

This word can elicit frowns from some behavior analysts, but even the most orthodox admit the role of establishing or motivational *operations* as antecedent to the actions of many contingencies. But, this is a highly constrained view of behavior–consequence relations that barely conceals a traditional "pleasure versus pain" perspective on consequent events. It is as if one had hardly left the contexts of delivering discrete events like rat pellets or M&Ms. More recently, emphases have been placed on PIEs (phylogenetically important events), as if we could only understand complex human behavior by tracing it back to biological selection through such events (e.g., Baum, 2012). No one will dismiss feeding, drinking, sheltering, foraging, mating, nurturing, sleeping, predator-avoiding, and other PIE-related behaviors as being unessential to proper living, but to invoke these as primary in addressing the sorts of behaviors I have discussed would remind me of the many "just-so" stories told by some evolutionary psychologists. Of course, evolutionary mechanisms had to play significant roles in brain development and accompanying capacities for curiosity, problem solving, abstraction, and other behaviors relevant to creative expression, but the details of how these emerged are matters for considerable debate (see, e.g., Kozbelt, 2019). However, the multiplicative, emergenic hypothesis of extreme giftedness discussed earlier, correctly predicts that such abilities are *not* transmitted to offspring, in other words, do not run in families. Thus, there are no mechanisms for adaptive selection—such gifted individuals are evolutionary dead ends. Of course, there are cases where eminence appears to run in families, but the level of giftedness I have emphasized seems truly exceptional.

One source of controversy here is the "intrinsic" versus "extrinsic" sources of motivational control in creative accomplishment (Amabile, 2018). Although no one doubts the role of intrinsic sources, extrinsic recognition has also been important to most, if not all, the individuals I have discussed. The literature reveals a long and contentious battle concerning the relative roles of intrinsic and extrinsic conditions and consequences on creative behavior. Although this is not the place to review this battle, I will note that some, like Amabile—who had originally emphasized that extrinsic reinforcers only discourage or suppress creative activities—have come to recognize the subtleties and complexities of behavior–contingency interactions and variations in contexts in addressing this issue. In my examples, the obsessive devotion to mastering fields like mathematics and physics from an early age clearly reflects what most would label "intrinsic" motivation, but this conclusion oversimplifies the case. Not only is there typically a supportive environment of parents, tutors, colleagues, and others, but, given sufficient talent, the better we are at doing something, the more we tend to do it—a dynamic interplay between effort and accomplishment. The background process here is being *effective*, gaining or being in control of our environment to achieve both value and truth (Higgins, 2012). Just how "motivational operations" apply to such a phenomenon as "the rage to master" is unclear to me.

I have already emphasized the dynamic interlocking of talent, expertise, and motivation in significant creative accomplishment. What I am calling motivation is not confined to some antecedent or establishing operations, but rather it is a condition endemic to the process itself and manifested in a number of ways. First, motivation can be seen in the early and relentless curiosity about the world and particular domains within it, such as mathematics and science. Second, there is the obsessive devotion to mastery of a domain—hours, days, months, and years of intense focus to gain those skills needed. As already mentioned, Ericsson has emphasized the immense hard work needed to achieve mastery; furthermore, he appears to believe most all of us might attain such skills if only we worked hard enough. But I think that the effects of proper practice will differ substantially depending on *who* is practicing—a von Neumann versus most anyone else, for an example. Even the so-called 10,000-hour rule may not apply—many extremely gifted individuals can achieve outstanding results in far less time, as illustrated in my brief case studies. It is clear that gains through practice are reflected in individual differences in talents (e.g., Macnamara et al., 2018).

Still, the perseverative passion in gaining immense repertoires is only a start. It is also manifested in the exercise of problem finding and solving. Here is a quote from Andrew Wiles, the mathematician who, working alone for 7 years, finally proved Fermat's Last Theorem:

> One enters the first room of the mansion and it's dark. Completely dark. One stumbles around bumping into furniture, but gradually you learn where each piece of furniture is. Finally, after six months or so, you find the light switch, turn it on, and suddenly it's all illuminated. You can see exactly where you were. Then you move into the next room and spend another six months in the dark. So each of these breakthroughs, while sometimes they're momentary, sometimes over a period of a day or two, they are the culmination of, and couldn't exist without, the many month's of stumbling in the dark that precede them. (Singh, 1997, pp. 236–237)

How do we understand such devotion? I am sure we are in the dark too.

Of course, being in the dark about the processes I have discussed in this article does not assign them to "magic" in some transcendental and unfathomable sense. I (and others) have used that word only in the sense that there are mysteries to be addressed that currently confound us—behavior analysts and everyone else alike. But scientists need mysteries to thrive—to look zealously and creatively behind Nature's curtain to see how her tricks are done.

Availability of Data and Materials Not Applicable

Compliance with Ethical Standards On behalf of all authors, the corresponding author states that there is no conflict of interest.

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