Creativity Patterns in the Production of Scientific Theories and Literary Fiction

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THE PROCESS of knowledge formation and transmittal can be studied historically, at the level of societies and their cultures, or at the level of the individual and over the course of an individual's life. Take scientific knowledge, for example. The production of scientific knowledge by an individual is often associated with the concept of "creativity." According to social scientists, scientific knowledge production can qualify as creative if such knowledge is novel, is useful (e.g., it leads to theoretical advances in a discipline, or new technological applications), and has high impact.[1] The concept of creativity, however, does not apply only to scientific inquiry, but also to human activities in many other domains such as, for the example, the arts. Whether similar or different types of creativity are involved in science and in the arts is a question that has generated a great deal of research. q1

Two important aspects of creativity have been identified by research in psychology and cognitive science. First, creativity is usually the product of a gradual and complex process, rather than of a sudden leap of imagination. Second, there is a relationship between previous knowledge and creative output. Specifically, it has been hypothesized that although one must have some knowledge within a field to be able to be creative, too much knowledge can hamper creative thinking.[2] In this view the relationship between knowledge and creativity should be shaped like an inverted U, with maximal creativity occurring with some middle range of knowledge.

Studies of creativity in academia often use age as a proxy for previous knowledge, under the assumption that older individuals have more knowledge of their particular field than younger individuals. The association between creativity and age has been assessed using metrics for either quantity or quality of work. For example, creativity in science might be measured by number of publications (i.e., productivity) or by the impact of a single publication. An early study of scientific productivity in relation to age reported that most productivity occurred between the ages of 30 and 45, with a peak between the ages of 35 and 40.[3] More recently, Dean Simonton showed that, on average, scientists publish their best work at age 39, with their first work appearing at about age 27. Specifically, physicists and chemists tend to peak productively at about age 38, while biological and biomedical scientists tend to peak at about age 40.5 and 42, respectively.[4]

Creativity and age have also been studied in relation to the quality of work. In these studies, Nobel Prizes or most cited works are often used as a metric since both tend to represent novel and impactful contributions.[5] For example, an analysis of 96 biomedical researchers who won a Nobel Prize between 1980 and 2010 found that their prize-winning work was performed at about age 40.[6] Likewise, using a sample of 150 Nobel Prize laureates in science, Cesare Marchetti noted that the median age at which Nobel Prize winners performed their prize-winning work was 34, 37, and 40 for physics, chemistry, and medicine, respectively.[7]

A different picture has emerged from studies of literary or artistic creativity. Philip Hans Franses found that winners of the Nobel Prize in literature, on average, published their best work just before age 45, while Scott Barry Kaufman and James C. Kaufman reported that fiction writers, on average, published their best work at approximately 43 years of age.[8] Therefore, it appears that writers produce their best work later than scientists (40–45 years for writers vs. 35–40 years for scientists). Studies of other artistic disciplines have demonstrated a similarly delayed peak in the production of top-quality work. In an analysis of 120 notable composers, Simonton found that, on average, composers wrote their best music at age 41.[9] For famous painters, the average age of their best piece, determined by highest auction price, was about 42 years old.[10]

Although most studies of creativity so far are consistent with the notion that there is an inverted-U-shaped relationship between knowledge and creativity, these studies have also shown that creativity patterns show significant variation both among individuals and between academic disciplines or fields of activity. The reasons why creativity (as measured by quality rather than quantity of work produced) shows a delayed pattern among writers and artists relative to scientists are not well understood. One possibility is that different "creativity rules" apply to artistic and scientific disciplines, depending on the type of knowledge that needs to be mastered before creativity can emerge. The existing studies of creativity, however, have some limitations that prevent generalizations. One limitation is that age at best work may not accurately represent how long it takes to reach peak creativity, as different people begin working in their field at different ages, and different professions have different prerequisites for entry. Rather than average age at best publication, a better metric for creativity is years between entrance into a field and publication of the individual's best work. The use of this metric has led to the discovery of the "10-year creativity rule," according to which individuals become "experts" in their fields and produce their best work approximately 10 years after the beginning of activity in a particular field.[11]

However, within both the sciences and the arts there may be different types of activities that operate according to different “creativity rules.”

Benjamin Jones, E. J. Reedy, and Bruce Weinberg found that scientists who won the Nobel Prize for theoretical work performed their work over four years earlier than those who won the Nobel for empirical work, and others have come to similar conclusions.[12] One possible explanation for this difference is that empirical discoveries and theories in science rely on different types of creativity, which are the product of convergent thinking and divergent thinking, respectively. The process of convergent thinking that results in creative empirical research involves taking known concepts and applying them to novel problems. In contrast, the process of divergent thinking that results in creative theoretical work is characterized by flexible thinking and production of new ideas.[13] While the characteristics of convergent thinking resemble what Thomas Kuhn refers to as “normal science,” the characteristics of divergent thinking more closely resemble the type of creativity implied by Kuhn’s “revolutionary science,” which involves flexibility in thinking and creating alternatives to long-held beliefs.[14]

Similar to the sciences, the arts too may be heterogeneous with regard to the creativity processes involved in producing high-quality works. For example, novelists have been shown to publish their best work later than poets.[15] While the reason for this difference remains unclear, it may be hypothesized that parallels exist between particular activities within the sciences and the arts with regard to the importance of divergent versus convergent thinking. This hypothesis implies that subfields with the sciences and the arts that rely more on convergent versus divergent thinking should exhibit more similarities in their creativity patterns than the sciences and the arts as a whole.

We propose that significant parallels may exist between the writing of original literary fiction (but not commercial fiction, which relies on rehashing of well-established formulas) and the formulation of new scientific theories. First of all, both literary novels and scientific theories are fictional narratives about how the world works. (Although scientific theories may later reveal to have predictive power in the real world, when they are initially formulated, they are the product of someone's imagination, just like literary fiction.) Second, both activities require significant divergent thinking and production of new ideas. Therefore, both novels and theories require narrative construction and synthesis of ideas into a coherent story. Based on these parallels, we hypothesize that the relation between creative output and preexisting knowledge should be similar for novels and scientific theories. This hypothesis leads to the prediction that the number of years between entry into a field (denoted by first publication) and greatest achievement (best publication) should be similar for novels and scientific theories. The previous study that came closest to testing this prediction was conducted by Evelyn Raskin.[16] Raskin's study, however, was not specifically focused on creativity but addressed a broader notion of "scientific and literary ability." Furthermore, Raskin's study was not limited to novelists but also included poets and dramatists, while the scientific theories taken into consideration were only limited to mathematics and the physical sciences.

In this study, we conducted a novel test of the hypothesis that a similar pattern of creativity exists for the formulation of influential scientific theories and for the writing of important literary novels. Unlike Raskin, we focused on novels that are recognized as literary masterpieces and that represent the highest quality work produced by particular writers. Moreover, we included in the analysis scientific theories from a diverse array of fields, encompassing physical science, life science, and social science. We predicted that the similarity between the creativity patterns of novels and scientific theories would be greater than that shown for any previous comparisons of scientific and artistic creativity.

To test our hypothesis, we analyzed 103 literary novels and 93 scientific theories and their respective authors. The novels were obtained from The Modern Library's list of 100 greatest novels and from winners of the Pulitzer Prize in Fiction (called the Pulitzer Prize in Novel pre-1947). If authors appeared more than once, the earliest work was used as an indication of their first "important" novel. (It should be noted that the creative peak may actually represent the beginning of their creative peak.) No living authors were analyzed.

The 93 scientific theories include 31 theories from each of three subcategories: physical science, life science, and social science. Physical science included physics, astronomy, cosmology, chemistry (except for biochemistry), and geology. Life science included all branches of biology and biochemistry. Social science included anthropology, sociology, and psychology. If a scientist was listed more than once (e.g., Albert Einstein with Special Relativity in 1905 and General Relativity in 1915), then the earliest theory was used as an indication of the scientist's first important theory. No living scientists were analyzed, and theories were obtained from various sources, including textbooks and various science prizes. A theory was taken into consideration only if (1) it could be attributed mostly to one scientist and (2) it had been published. Theories are sometimes produced over long periods of time with input from several individuals. Thus, to get at divergent thinking as it relates to creativity, the first publication that laid out the theory's main concepts and described it was used as the date of publication for the theory.

Once the first important publication of a particular author was identified, his or her entry to the professional field, denoted by first publication, was assessed. In the case of novelists, the first publication of either a novel or a short story was used. For scientists, the first publication in the general field (i.e., physical science, life science, or social science) of the theory was used. If a publication was not present before the submission of a PhD dissertation, then the dissertation was used as the first publication (as long as it fell into the general field of the theory).

Table 1 displays the mean, median, standard deviation, minimum, and maximum for age at first publication for novelists and scientists. Table 2 displays the same statistics for age at first important publication, and table 3 for the number of years between first publication and first important publication. For scientists who formulated important theories, the median age at first publication was 27, the median age at first important publication was 39, and the median interval between first and most important theoretical publication was 10.0 years. The median interval between first and most important publication was lower for physical scientists (8 years) than for life scientists (12 years) and social scientists (13 years). There were no significant correlations between birth year and age at first publication, first important publication (best work), and years between first and best publication.

For novelists, the median age at first publication was 29, the median age at first important publication was 41, and the median interval between first and most important work was 10 years. Therefore,

Table 1. Age at First Publication

Group	**Mean**	**Median**	**St. Dev.**	**Min**	**Max**	**N**
All novelists	30.0	29.0	8.0	13	57	103
All scientists	26.5	27.0	4.2	14	40	93
Phys. scientists	24.7	25.0	3.8	14	32	31
Life scientists	26.7	27.0	4.3	18	35	31
Soc. scientists	28.1	28.0	3.9	23	40	31

Table 2. Age at First Important Publication

Group	Mean	Median	St. Dev.	Min	Max	N
All novelists	41.6	41.0	10.8	23	76	103
All scientists	38.0	37.0	8.3	22	62	93
Phys. scientists	34.2	34.0	7.5	22	56	31
Life scientists	39.0	38.0	8.6	25	58	31
Soc. scientists	40.7	41.0	7.6	26	62	31

on average, novelists entered the field and produced their best work slightly later (about 2 years) than scientists. Novelists were very similar to social scientists in terms of their age at first publication (28 vs. 29) and age for best work (41 for both), but a bit further apart for the interval between first and best work (10 vs. 13 years). There were no significant correlations between birth year and age at first work or birth year and age at best work. There was a significant negative correlation, however, between birth year and years between first and best publication ($r = -0.19$; $p < 0.05$), suggesting that the number of years between first and best publication has been decreasing over time for novelists.

There was considerable variation in age at first publication, first best publication, and years between, for all groups studied. However, novelists have a noticeably higher standard deviation than scientists in any discipline. Figure 1 displays box plots for each field of science as

Table 3. Years between First and First Important Publication

Group	Mean	Median	St. Dev.	Min	Max	N
All novelists	11.6	10.0	11.1	0	44	103
All scientists	11.5	10.0	7.8	0	36	93
Phys. scientists	9.4	8.0	7.1	0	30	31
Life scientists	12.3	12.0	8.7	0	36	31
Soc. scientists	12.6	13.0	7.3	1	29	31

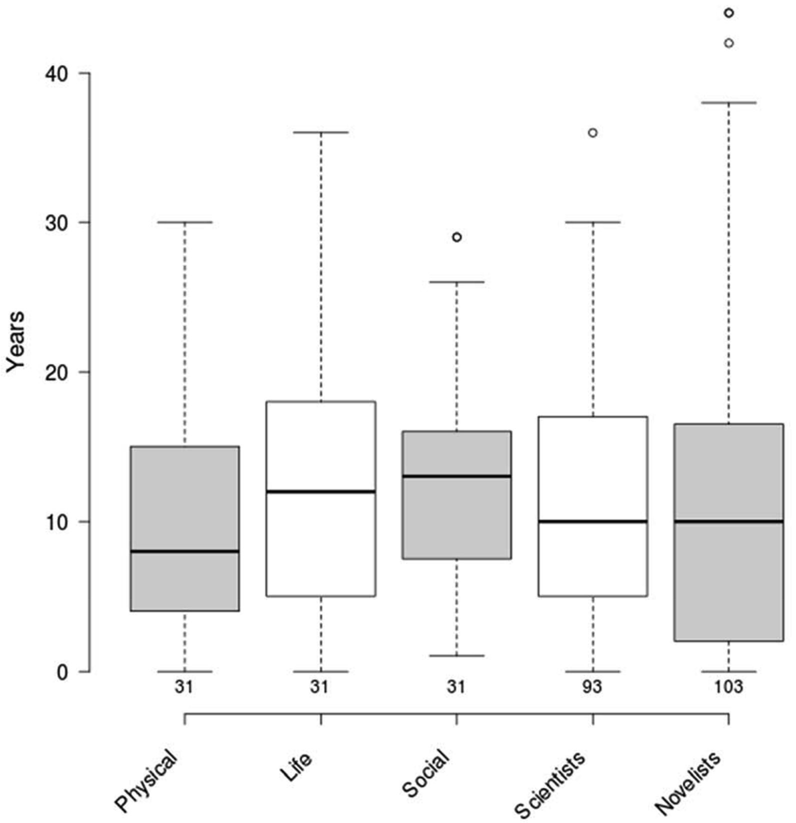

Figure 1.
Box plots for years until first important publication.

well as for all scientists and all novelists. For years between first publication and first important publication, life scientists had the largest variance and interquartile range among scientific fields, and social scientists had the smallest variance and interquartile range. For both novelists and scientists, at least 75% of individuals published their first important work 17 years or less after their first work.

Novelists and scientists who published their first work before the median age at first publication (referred to as "early publishers") were

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compared to those who published their first work after the median age at first publication (referred to as "late publishers"). Though median and mode were relatively close in most analyses, median was used instead of mode, as the latter can be influenced more heavily by skewed distributions. Among scientists, there was no significant difference in average years between first publication and first important publication for early and late publishers. However, an interesting trend did emerge such that early publishers in science had two peak averages around 10 years and 20 years between first and first important (fig. 2). This is likely due to physical scientists, who peak early, making up the first peak and to social scientists, who peak late, making up the second, with life scientists spread evenly among the two (fig. 1). The differences between early- and late-publishing novelists were much more obvious than those between the scientists. Late-publishing novelists published their first important work significantly ($p < 0.001$) sooner than early-publishing novelists (table 4 and fig. 3). Part of this large difference is due to a large number of late-publishing novelists whose first publication was also their first important or major career publication.

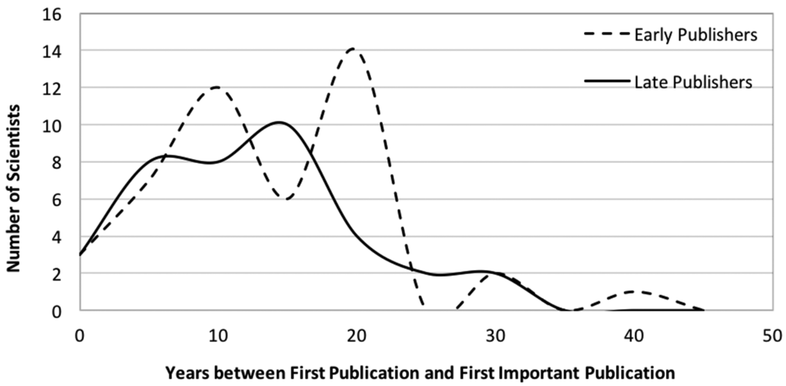

Figure 2.
Early versus late publishers among all scientists.

Table 4. Early vs. Late Publishers in Novelists and Scientists

Group	Early Publishing Scientists	Late Publishing Scientists	Early Publishing Novelists	Late Publishing Novelists
Avg. between 1st and 1st important (years)	12.4	10.7	15.5	8.0
Age at 1st publication	Before 27	After 27	Before 29	After 29

Figure 4 more clearly illustrates the spread of data between early-publishing and late-publishing scientists and novelists. Late-publishing novelists stray from the other three groups when it comes to time between first publication and first important publication. In fact, the first published work was also the first important work for 31 percent of late-publishing novelists, compared to 8 percent for early-publishing novelists, 7 percent for early-publishing scientists, and 8 percent for late-publishing scientists. Moreover, 75 percent of late-publishing novelists published their first important work within 12 years, a full decade before their early-publishing counterparts. Interestingly, this bias toward very early important works did not seem to have a strong effect

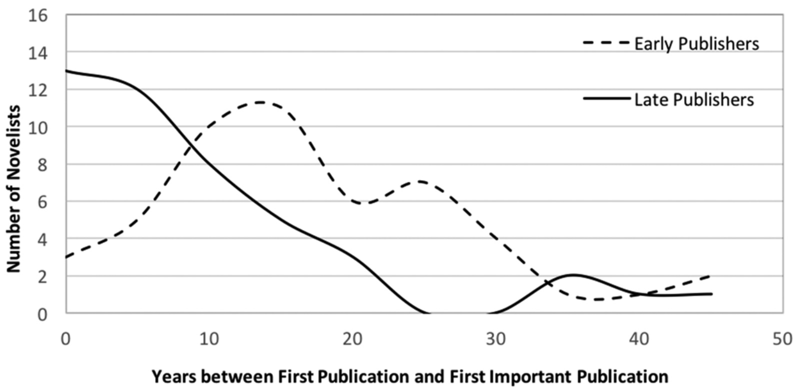

Figure 3.
Early versus late publishers among fiction novelists.

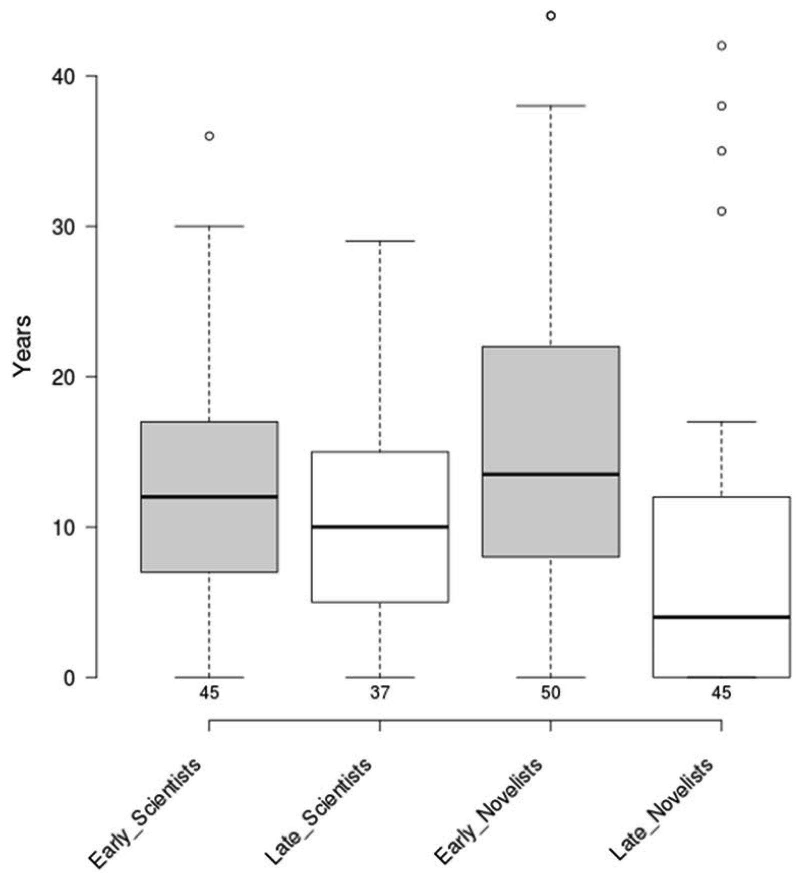

Figure 4.
Box plots for early- and late-publishing scientists and novelists.

on the variance of years until important work in late-publishing novelists.

Overall, the main hypothesis of our study, that there would be significant similarity between the creativity patterns of scientists who formulate impactful theories and fiction writers who write important novels, was supported. Specifically, the median interval between entry into the field, as indexed by the first publication, and the publication of first major work was 10 years for both novelists and all scientists combined. This result strongly supports the 10-year creativity rule.[17] It also suggests that the rule is especially likely to apply when creativity is measured by quality rather than quantity of work, and when comparing creative outputs that require divergent thinking to a similar extent, such as scientific theories and novels.

There are some other important similarities and differences between the results of this study and those of previous studies. The beginning of the "peak age," denoted by age at first important publication, for scientists follows trends that have been previously found in studies of Nobel Prize winners.[18] The median age at first publication for all scientists, 27, and median age at first important publication, 39, were the same as those reported by Simonton.[19] However, when broken down by field, the results from this study show that physical scientists and life scientists peak a few years earlier (at age 38 and 40.5, respectively) than shown by Simonton. Age at first publication for these fields was also shown to be a few years earlier than previously reported. One explanation for this difference could be that Simonton included scientists from 1450 until now (excluding living scientists), with 1790 being the median birth year for the sample. This extends much further back than the current analysis, where the median birth year was 1900 (mean 1881) and all but one scientist (Newton) was born in the eighteenth century or later. Thus, differences between our results and those by Simonton may reflect differences in the process of scientific publication between the pre-scientific-journal era and the modern scientific journal era.

The novelists analyzed in our study published their best work at around age 41, which is considerably younger than age 45 for Nobel Prize laureates found by Franses, and somewhat younger than age 43 for fiction writers found by Kaufman and Kaufman, but closer to the age at best work for painters, 42, and composers, 41, reported by some previous studies.[20] Novelists showed a slightly later age at first impor-

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tant publication when compared to all scientists. Interestingly, the age at first publication and the age at first important publication were very similar for novelists and social scientists, yet the average number of years between was not similar. This finding suggests that the type of creative process involved in writing novels may be particularly similar to that underlying social science theories, possibly because both social science theories and novels deal with human psychological and behavioral processes and require similar degrees of interpretation and speculation.

The standard deviation for age at first publication for novelists was about twice as large as that of all scientists, regardless of their discipline. This is likely due to the fact that scientists tend to enter the field around the same age due to doctoral training that is required for them to truly be a part of the scientific community. Novelists, on the other hand, may or may not hold a doctorate. While this may account for the variation, it does not explain the relatively later average age at first publication for novelists.

To further explore individual differences in creativity in our sample, novelists and scientists were split around the median into two groups: early publishers and late publishers. While early-publishing novelists took about 15.5 years to publish their first great work, late-publishing novelists published their first great work significantly earlier, only 8.8 years on average after their first publication. Part of this large difference is due to a large number of late-publishing novelists whose first publication was also their first important or major career publication. In contrast, the interval between first and most important publication was not significantly different between early- and late-publishing scientists. The reason for this difference between novelists and scientists remains unclear and warrants further investigation. It is possible that early-publishing novelists and late-publishing novelists in this study represent two distinct types of writers—conceptualists and experimentalists. If this is the case, it would be inter-

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esting to compare early-publishing "conceptual" novelists to scientific theorists and late-publishing "experimental" novelists to empirical scientists.

Previous research has suggested that the age at which great achievement occurs in science is increasing. We did not find any significant correlations between birth year and age at first work, birth year and age at best work, or birth year and years between first work and best work for scientists or novelists. There is a notable exception. On average, physical scientists involved in the quantum revolution published their first important work just before age 32 and had only 6.7 years between their first publication and first important publication, about 4 years sooner than other physical scientists. As would be expected, scientists are able to publish significant theoretical work earlier during a paradigm shift like the quantum revolution due to less need for attaining knowledge relating to the prior paradigm.

Going back to the main finding of this study, which provides evidence for the applicability of the 10-year creativity rule to both scientific theories and literary fiction, it is possible that in addition to the role of divergent thinking, other factors may be responsible for similarities in creativities across these fields. For example, both scientific theories and literary fiction are influenced from the sociohistorical context in which their authors are situated. Future studies that compare creativity between scientific theories and novels should carefully examine the life histories of creative individuals within their sociohistorical context in an attempt to elucidate the mechanisms responsible for the 10-year rule. More generally, this area of investigation could benefit from an interdisciplinary effort that includes expertise from anthropologists, sociologists, biologists, psychologists, and neuroscientists, among others.

For example, scholars who study the history and sociology of science and literature can provide interesting perspectives on creativity in these fields, while brain-imaging studies of creative thinking in science and literature can provide new evidence on the cognitive and neural bases of creativities in these activities. Finally, although age is often used by creativity researchers as a proxy for an individual's knowledge in his or her field, a comprehensive test of the hypothesis that the relationship between knowledge and creativity has the shape of an inverted U (with maximal creativity occurring in conjunction with an intermediate amount of knowledge) requires a more direct measure of knowledge than that provided by age.

Notes

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