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## **The role of knowledge structures in adult excellence. An approach from expert functioning**

### **El papel de las estructuras de conocimiento en la excelencia adulta. Aproximación desde el funcionamiento experto**

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### **Abstract**

Adult performance of high ability individuals has seldom been researched. Current results suggest that adult excellence occurs at lower rates than high ability individuals identified in their infancy or youth, with few cases of high intellectual abilities among adults that yield excellence products. This paper focuses on the analysis of the relative frequency of biographical traits that are associated with high ability as well as to the opportunities that allow building particular knowledge structures that are non-conventional and support innovation in people who excelled. A retrospective biographical analysis was performed on a sample of 120 individuals that generated renowned excellence products, in different fields, in the XXth century. Variables associated to high abilities were: precocity; learning problems; social problems in school; and academic excellence. And the variables associated with the generation of knowledge structures that support innovation were: academic-professional continuity; strong influence of particular individuals; and high productivity. Significant differences were found, showing a low presence of the first four variables and a higher presence of the last three. It follows that the trajectory towards excellence does not seem to correlate with a high level of intellectual resources but with a certain use of sufficient resources, whether cerebral or external technological support.

### **Resumen**

El rendimiento adulto de personas con diagnóstico de alta capacidad es un campo que ha sido poco investigado. Los resultados existentes indican que la excelencia se presenta en proporciones mucho menores que los casos con alta capacidad detectados durante la infancia/juventud, siendo relativamente pocos los casos



de alta capacidad entre las personas que han generado productos de excelencia. Este artículo plantea el análisis de la frecuencia relativa de variables biográficas asociadas a la alta capacidad y a la oportunidad de generación de estructuras de conocimiento particulares, adecuadas para soportar la innovación en personas que han demostrado excelencia. Se ha utilizado un análisis biográfico retrospectivo de una muestra de 120 personas que generaron reconocidos productos de excelencia en diferentes campos durante el siglo XX. Se evaluaron variables asociadas a las altas capacidades: precocidad, problemas de aprendizaje, problemas sociales en la escuela y excelencia académica. Y variables asociadas a la generación de estructuras de conocimiento innovadoras y no convencionales: continuidad académico-profesional, influencia de personas individuales y alta productividad. Se detectaron diferencias significativas que indican una baja presencia de las primeras cuatro variables y una elevada presencia de las tres últimas. De ello se deduce que la trayectoria hacia la excelencia no parece corresponderse con la disposición de un elevado nivel de recursos intelectuales sino con una determinada utilización de recursos suficientes, ya sean cerebrales o apoyos tecnológicos externos.

## Keywords / Palabras clave

Excellence, expertise, knowledge structures, high ability, brain, technology, innate, adult.

Excelencia, experto, estructuras de conocimiento, alta capacidad, cerebro, tecnología, innatismo, adulto.

## 1. Introduction

In adulthood, the concept of excellence is associated with the production of exceptional results, measured on an absolute scale. Excellence depends only on the results achieved or the products created and, in order to be considered excellent, the products must be marked by a high level of quality and an innovative or even revolutionary character (Campitelli & Gobet, 2008; Gobet, 2016). In order to identify products of excellence, it is necessary to observe the degree of social recognition they obtain. This recognition is based upon the technical, conceptual, instrumental or practical value offered by the product in question. This notion of recognized value transcends the mere winning of awards or garnering of official titles. The product must exert a real and significant influence on others who, in turn, recognize its utility and importance. The Internet, for example, could be considered a product of excellence due to its widespread social acceptance, as it has been embraced by a broad range of people. Its technical effects have been revolutionary, and it has had a far-reaching influence on the progress of the field of computer science and the way we access information (Blyth, 2013; Salinas, 2003). It is a product's effects, then, that mark it as excellent.

Meanwhile, the conceptual value of scientific contributions lies in the influence these contributions have on the next generation of scientific approaches or technical applications. Thus, the scientific 'products' of Newton and Einstein can be considered to exhibit excellence in light of the heuristic impact they have had on generations of physicists and engineers (Simonton, 2016). The excellence is certified by this lasting effect, not by recognition in the form of titles (Newton's knighthood) or awards (Einstein's Nobel Prize, which in fact was not given for the scientist's most significant work). Worth of special consideration is the degree to which a product of excellence is identified with the person (or people) who created it. The most common explanation for excellence is that it emerges from an intrinsic characteristic of the person who created the product that is often called 'intelligence' (Neubauer & Opriessnig, 2014). Although this connection between the characteristics of the product and this underlying capacity is somewhat intuitive, this link is subject to some fundamental confusions:

- 1) The explanation appeals to a construct defined by its own product: the capacity for excellence because it produces excellent products. There is no explanation of how intelligence has generated this product or what representations and cognitive resources were employed to create the product.



2) The product would have to be somehow fully contained in the individual's brain structures. In other words, biology would have had to anticipate the social and cultural context in which the product would make sense.

3) If it is true that this underlying capacity exists in an absolute form, then the person should be able to generate products of excellence in any field.

The tendency to attribute excellence to individual characteristics is aligned with a tradition that views intellectual functioning as innate. Thus, the structural elements of an individual (mainly his or her brain) are considered the determining factors that allow a product to be generated (Singh & O'Boyle, 2004). This perspective equates the quality of a product with that of the physical system that created it (Mrazik & Dombrowski, 2010).

This innatist approach seems to partly fit with what scientists now know about the brain-mind-product relationship. It is true that the brain must physically undertake the representations and operations necessary to generate any given product. This does not mean, however, that *only* the particular brain that generated a product is capable of undertaking these representations and operations. Contemporary knowledge also explains that a brain can be used in a number of different ways, which is what allows us to adjust to different cultural contexts (Richardson, 1993). In fact, there is no evidence to suggest that human brains that existed, for example, during the Roman Empire were any different from contemporary brains. However, the cultural conditions they were forced to contend with were very different, particularly when it comes to technology.

The alternative explanation to this equivalency between the underlying structure (the brain) and the product does not deny the existence of certain minimum conditions in terms of cognitive power. This perspective admits that not *all* brains are capable of undertaking certain representations and operations. Nonetheless, the existence of these cognitive resources is not sufficient. They must be expressed in the right way in order to lead to the creation of a product of excellence (Castelló, 2001). The aim of this paper is to investigate whether excellence is an intrinsic property of an individual or whether it emerges from an exploitation of their cognitive characteristics—from how they are used to represent and process. Hence, the physical structure (the brain) remains a necessary (although less definitive) condition, while the functional layer (the management and organization of knowledge) plays a key role in exploiting this physical foundation in the form of exceptional performance (Castelló, 2002).

## 1.1. Cognitive appendages

One of the most remarkable characteristics of the technological advances of the 21<sup>st</sup> century is that they often serve to support us in our own cognitive functions (Onrubia, 2016). The information age has been marked by the appearance of technology that is able to store and process information. While it is true that information storage already existed thanks to the advent of writing systems and other formats such as painting and photography, IT systems have brought with them an explosion in humans' capacity to store, access and process information.

These technological changes have meant that some parts of human cognition, such as memory, can function in conjunction with external technological 'appendages'. With fast enough access and reliable media, there is no reason not to use one's own brain and external resources simultaneously (Costa, Cuzzocrea, & Nuzzaci, 2014). These external resources can be defined as cognitive appendages, and they are not significantly different from traditional cognitive resources of individuals (or, if they are, they may in fact be better in some respects). This does not mean that they completely supplant mental functioning; they rather complement or enhance some cognitive functions. It is worth noting that external memory stores already existed in the form of books, for example. In the past, no one found it shocking when a person used a library rather than memorizing all the information he or she might need. Much like libraries before them, the advances in computing power of IT systems have driven huge improvements in functionality, completing the same sort of operations as a human brain, but doing them so much faster and with greater reliability. Thus, when a certain process



requires millions of calculations, there is no shame in allowing them to be done by a computer rather than a human mind (Castelló, 2001).

Taken as a whole, the existence of these cognitive appendages has meant that there are less demands placed on the human brain in terms of the representations a brain must undertake and the processing it must carry out. This frees up cognitive resources and energy that the brain can use to 'manage' the cognitive system, which in turn is assisted by a range of physical supports. Thus, it is possible to attain high levels of functioning in areas such as memory or calculation (among others) without needing to devote too much time or energy to these tasks. This time and energy can then be expended on functions that work to integrate one's cognitive resources with external resources. For example, some information might be stored in the brain, while the bulk of the details might be kept in external memory (Castelló, 2002), or the planning, undertaking and supervision of processes might be done by the brain itself, while the execution of mechanical computations is carried out by external devices.

In this context, the belief in the innate nature of intelligence is much harder to sustain. A perspective centered on the use of the brain and the construction of functions becomes much more powerful as an interpretive framework in these circumstances. It can show how one can benefit from newly available physical support mechanisms while at the same time maintaining the ability to coordinate these physical resources and apply them to useful functions. For instance, most people can now access the boundless information that is available on the Internet, but what sets one person apart from another is their ability to exploit this information. This represents a change in the way brains work. Carrying out mechanical operations is no longer as important as the ability to organize and supervise large processes, especially those that are not subject to being guided by algorithms (Klein, 1992).

## 1.2. An unfulfilled prophecy

Over the course of the 20<sup>th</sup> century, the tradition of research and explanations employing the sort of innatist approach that dates back to Galton (1869) became the dominant paradigm, and these approaches are still in widespread use today. According to this perspective, unusual skills or abilities are explained by biological traits corresponding to the results obtained on certain tests (often IQ tests) (McLain & Pfeiffer, 2012).

The underlying assumptions here include: 1) the existence of a construct called 'intelligence', defined as a person's general cerebral capacity and thought to determine his or her performance in all fields of life; 2) the possibility of measuring this construct via scores obtained on certain tests (such as IQ tests); 3) the stability of an individual's intelligence and his or her IQ over time, given that intelligence is viewed as a structural, biological trait; and 4) the existence of differences between individuals in terms of this construct that are reflected in the variations in the scores obtained on these tests.

Thus, there is an expectation that people who score highly on IQ tests (usually defined as those whose scores are two standard deviations or more above average) will be most likely to be able to perform at an exceptional level throughout their lives. However, this prediction is not borne out by the facts. Firstly, many more people have scored over 130 on IQ tests as children or adolescents than have achieved excellence as adults, as defined above. Secondly, most adults who perform excellently did not record such outstanding IQ scores as children.

These data alone would seem to provide overwhelming proof, but it is still worth taking a closer look at what might be behind these discrepancies between expectations and actual performance. One way of examining this issue would be to look at the longitudinal study in which Terman (1925) and his collaborators followed 1,624 California children until they reached adulthood (Terman & Oden, 1959). The participants were selected for the study because they had scored over 130 on the Stanford-Binet test that had been administered to all the 12-year-old students in the state. These high-scoring students were then compared to the rest of their peers and were found to be more physically mature at the age of 12, to display better academic results, to reach more advanced degrees, to have higher income levels and better health as adults, to have more marital stability and



to produce more scientific articles. Terman and his colleagues believed the results to provide an empirical foundation for the theory that intelligence is innate by showing that the effects of greater biological gifts were felt in all areas of life.

Subsequent researchers who reviewed this study (Simonton, 2014) pointed to alternative explanations for the data that are much more convincing. Chief among these critical arguments were: 1) the link between IQ and academic intelligence, given that performance in school was the variable most accurately predicted by this index; 2) the lack of weight given to the consequences of this greater academic ability, with better grades leading to more years of school completed and in turn to better-paid professions; 3) the neutralization of variables such as health or marital stability, justified by the higher income received by these individuals. The most important critiques, however, had to do with the productivity of the group studied. None of them was responsible for any exceptional accomplishments, while among the population of California of the same age were some very accomplished individuals who had not scored above 130 on the test, including William Shockley and Walter Alvarez, winners of the Nobel Prize for Physics (Simonton, 2016).

All of this would seem to point toward two conclusions. First, the theory of innate intelligence and the definition of intelligence via IQ seem to have some major weaknesses. Second, a high IQ as a child does not seem to be a necessary condition for excellent performance as an adult.

### 1.3. The foundations of adult performance and expert functioning

Research in this field published since the last two decades of the 20<sup>th</sup> century tends to use a different kind of interpretive framework, based on recent advances in neurology and cognitive science (Di-Rosa, Cieri, Antonucci, Stupia, & Gatta, 2015). These advances have shed light on important aspects such as how cerebral resources are translated into brain functioning, the use of these functions to generate knowledge structures and the use of these structures as the basis of logical and creative functioning, as well as the integration of perceptive elements, decision making, and response in the consolidation of competences (Castelló, 2002).

The clearest example of these characteristics, confirmed by excellent performance, is the so-called 'expert model' (Simonton, 1999). It should be noted that this model refers to a specific way of using the available resources, aimed at the creation of solid knowledge structures which, in turn, form the basis for improved competences in terms of perception, reasoning and response. This model has nothing to do with the more commonplace use of the term 'expert', associated with people who are especially knowledgeable or experienced with regard to a given topic (Simonton, 2014).

The accumulation of experience and information is a necessary but not a sufficient condition in order to achieve expert competency. For this to happen, the experience and information must be organized in a particular way (Greene & Hunt, 2017; Shimizu & Okada, 2018). Specifically, the representations generated must employ the available resources of representation in the most efficient way for a given individual, thus allowing them to be processed in an efficient way. Meanwhile, the knowledge structures that are formed by these representations must have been reorganized on a number of occasions, thus establishing multiple connections among the elements that make them up. These connections will make it possible to notice undetected relationships or to form new ideas (Daly, Yilmaz, Christian, Seifert, & González, 2012; Yilmaz & Seifert, 2011).

It should be highlighted that the kinds of knowledge structures generated by education systems (at any level) do not meet these conditions due to both the medium in which the content is conveyed (usually verbal) and to a style of organization that is often addressed to generate logical, unconnected structures (Alonso-Tapia, 2002). Academic performance is not based on converting verbal format into other forms of representation that might be more effective for an individual, nor is it founded on modifying the organization of the contents. This means that those who are the best at absorbing contents in an academic setting will be able to apply what they have learned, but they will be unlikely to innovate. The education system tends to inhibit divergent or creative thought in favor of logic and conformity (Robinson & Aronica, 2015).



Unlike academic learning, experiential learning is not pre-structured, nor does it have to come in any specific representational format. The learner herself does the task of representation (in a way that is best suited to her resources) and detects or forms relationships between representations. The consequence is that the resulting knowledge structures are much better suited for use by the person who has generated them, even though they might be difficult to transmit to others with distinct representational characteristics (Castelló & Cladellas, 2013). That is why attempts to transfer the expert knowledge of people who have created products of excellence to non-experts have met with little success.

Obviously, very positive results cannot be achieved by a brain lacking in resources of representation, but it is not necessary to have exceptional resources either. At the core of this approach is the idea that each individual can succeed by using the most of the resources they have available, as long as they are sufficient, and by devoting a lot of time and effort to using these resources to reorganize knowledge. All of a person's cognitive activities, then, can benefit from 'customized' knowledge structures, which lead to improvements in perception and decision making and to greater complexity of knowledge. As these knowledge structures are generated seamlessly, they can smoothly and naturally expand via new experiences or they can be reorganized to accommodate new data (Castelló, 2002).

This kind of cognitive configuration also has advantages when it comes to the use of resources in the form of cognitive appendages. For example, efficient perception patterns make it easier to access information online and to select materials (new or otherwise) that are consistent with one's existing knowledge structures. These same structures also make it possible to understand and assess meaning from the information found online. Additionally, in a well-structured decision-making process an individual can use external resources to address the more mechanical steps and reserve his or her brain-mind for supervisory tasks and the integration of results.

Expertise is attained by people who are able to exploit the cognitive resources at their disposal in certain ways, as the result of a pattern of development, articulation and adjustment of capacities, not because of the presence of extraordinarily efficient capacities. The term 'deliberate practice', coined by Ericsson, Krampe, & Tesch-Römer (1993), is often associated with expertise. This sort of practice is useful when it can be applied to this kind of exploitation of resources and used to confirm the knowledge generated via feedback from other experts, bringing knowledge ever closer to the object represented. This kind of knowledge could not be further from the stagnant sort of knowledge that comes from instruction (Hambrick & al., 2014; Sala, Foley, & Gobet, 2017).

Despite the proven relationship between deliberate practice and expertise (especially when it comes to cognitive activities) it should be noted that practice in and of itself is not enough to become an expert in a field like chess or sports. Other factors (such as the age at which one started the activity, childhood experiences and other activities apart from the area of expertise) play at least as important a role in the achievement of expertise (Gobet, 2016; Hambrick & al., 2014; Hodges, Kerr, Starkes, Weir, & Nananidou, 2004; Macnamara, Hambrick, & Oswald, 2014).

## 2. Material and method

### 2.1. A bibliographical analysis of excellence in performance

A number of researchers including Cox (1926) and Simonton (2009) have used the technique of bibliographical analysis to shed light on developmental processes. The greatest strength of this method is that it allows for the analysis of individuals who have created really exceptional products in a situated context. If one is to analyze the biography of Picasso, one might be completely certain of the exceptional nature of his artistic production, though one would be approaching the subject from a post-hoc perspective. Using such a method, the researcher might detect certain associations that suggest a causal relationship. A more quantitative approach that looks at a number of cases simultaneously makes it possible to gather more descriptive data and establish more solid associations, although it does not offer any certainty in terms of causality.



This limitation does not prevent such a methodology from being able to test certain specific hypotheses derived from theoretical explanations. The null and alternative hypotheses are as follows:

H0. If the innatist theory of intelligence were accurate, one would expect to find that in most cases the individuals displayed high performance in childhood or adolescence (precociousness), as well as high IQs.

H1. These traits appear in less than half of the sample, while a majority of the sample display indicators of the gradual construction of knowledge structures.

## 2.2. Sample

The random, non-stratified sample was selected using the *Chambers Biographical Dictionary* (1997). Random two-digit numbers were used to select pages of the volume, and the person described on the page was included in the sample, as long as his or her accomplishments during the 20<sup>th</sup> century. Otherwise, another random number was selected and added to the previous number. This procedure was repeated until the end of the dictionary and until a sample of 120 people had been chosen. The fields of the people's excellent accomplishments are detailed in Table 1.

Field	Cases
Philosophy	11
Politics	28
Science	12
Sports	14
Visual arts	12
Music	22
Literature	21
Total	120

## 2.3. Procedure

After the selection of the cases, the individuals' biographies were read in detail to seek out the following information about each person, which made up the list of variables to be assessed:

1) Precociousness: generation of excellent products in childhood; 2) Learning problems; 3) Social problems at school (conflicts with classmates or teachers) 4) Academic excellence: exceptional academic performance at any level of study; 5) Academic-professional continuity: professional activities related to the education received; 6) Intense influence from certain individuals 7) High productivity: generation of abundant products of excellence throughout life.

All the variables were binary and were assigned a value of 'Yes' when the biographical description made reference to the issue and 'No' if it did not. The value yes/no was assigned independently by three researchers, who were in complete agreement in 87.1% of the cases (627 of the 720 values). In the remaining 12.9% of cases, the value chosen by two of the three was used.

The first four variables correspond to expectations that would exist according to an innatist model and, more specifically, according to the most common description of people with high IQs during childhood and adolescence. Variables 5, 6 and 7 correspond to descriptions associated with expert functioning.

## 3. Results

The occurrence of each of the variables is presented in Table 2. The Chi-squared statistical test was applied to compare the percentages of cases that displayed a certain trait with those that did not. The null hypothesis would suggest that the traits associated with the first four variables should be



dominant and should display significant differences. The alternative hypothesis, meanwhile, would be supported if there was a predominance of the characteristics described by the final three variables. Given that there were only two possible values for each variable, significant values nearing 50% should be interpreted with a great deal of caution. However, values for which one of the two percentages is at least twice the other percentage can be considered solid indicators, even with the 12.9% level of error presented in section 2.3.

Biographical trait	Percentage	Chi-squared	p
Precociousness	20.6%	37.093	0.000
Learning problems	1.9%	99.150	0.000
Social problems at school	3.7%	92.593	0.000
Academic excellence	21.3%	35.593	0.000
Academic-professional continuity	95.4%	88.926	0.000
Intensive influence from certain individuals	92.6%	78.370	0.000
High productivity	68.5%	63.722	0.000

As is clear from Table 2, all the variables display a high degree of significance. The first four variables show low or very low values, while the last three display high values. In all cases, beyond the statistical significance, the magnitude of the differences between the values meets the criteria that one of the percentages must be at least twice the corresponding opposite value.

## 4. Discussion and conclusions

The results of the study somewhat echo those obtained by Simonton (1997) and contrast with those of Terman (1925). They indicate that most of the individuals in the sample did not show signs in childhood that would have made it possible to predict their performance as adults. Specifically, the percentages of precocity (20,6%) and academic excellence (21,3%), variables that tend to be most associated with high IQ, were present in only about one out of five cases. Meanwhile, learning and social difficulties, some of the stereotypical problems often attributed to highly gifted children and adolescents, appeared only in very small percentages, providing evidence that these phenomena are less associated with cognitive ability than with personality characteristics (McCrae, 1996; Overskeid, Grønnerød, & Simonton, 2012) or with passing circumstances.

The fact that academic-professional continuity is present in nearly all members of the sample would indicate that stability is a key factor in the development of solid knowledge structures in accordance with individual's specific resources. In contrast, precarious employment and professional instability can put individuals under strong economic pressure and leave them in jobs to which they are ill-suited. Both factors may undermine or erode the formation of personalized knowledge structures and encourage other more conventional structures, suited to meeting immediate needs.

The variable that examines the influence of individuals is also very revealing in that it shows that the people in the sample tended to develop more along personal than along institutional lines. This variable makes clear that the participants were able to exercise a critical capacity and to choose to follow the examples of certain respected individuals, rather than taking the established path set out by institutions (Ericsson & al., 1993). People who create exceptional things do not tend to follow established schools of thought or the latest trends. Instead, they seek out ideas and advice from outside the mainstream. This search for influences out of the mainstream also indicates a tendency for creativity. By definition, creative people tend to stray from the most common paths, which makes it possible for them to create innovative products.

Finally, many of the members of the sample are marked by high productivity, although the presence of this variable is less pronounced than others (68.5%). There are two explanations for the moderate prevalence of high productivity. First, the main efforts of people with expert functioning focus on the creation of efficient knowledge structures and their optimization before they being to create products.





However, the tendency of these people to innovate means that many of them end up creating a lot of products as they experiment with different alternatives. Thus, the figure found for this variable represents a middle ground caused by the existence of cases where the creation of products is postponed until knowledge structures are consolidated and of cases where individuals explored multiple options in the exercise of their creativity (Henriksen, Mishra, & Fisser, 2016).

Overall, the results point to two main conclusions and a corollary. First, excellence in adulthood does not seem to be associated with the traditional profiles of gifted children, at the very least in the way they are assessed. High IQ predicts academic performance, and undoubtedly this performance is linked to both good training and to the attainment of prestigious positions. However, people who develop along these lines tend to be conformists, and they tend to accept the mainstream. It stands to reason that following mainstream trends is not very compatible with innovation, and even less so with revolutionizing a given field. Nonetheless, the products they generate can still be valuable, as they are often linked to incremental improvements in knowledge, techniques or materials, all of which play an important role in the progress of a discipline. True innovation, however, is found elsewhere. Secondly, the ability to exploit one's own cognitive resources along the lines of expert functioning and to build up strong and complex knowledge structures does not necessarily require extraordinary natural gifts. Instead, this kind of cognitive activity is focused on the effective use of moderately high levels of resources. The decision-making processes of these individuals, then, are based on the creation of highly elaborate knowledge structures, built thanks to their efforts to optimize representations and, more specifically, the connections between represented elements. It is true that the range of representational resources offered by a given brain (or by other kinds of technological supports) is important, but the key lies in how these resources are systematically employed to attain a kind of knowledge that is customized to a given individual. Thus, the amount of information stored is less important than the quality of its organization. Information should be kept so as to allow each individual to represent it in the way best suited to herself, and to ensure that the greatest possible number of connections are forged.

The corollary is that the road to excellence is not an easy one, as a number of obstacles can get in the way. The lure of immediate prestige, well-paid conventional jobs and society's lack of acceptance of innovative ideas are only a few of the stumbling blocks that can hinder a person on the path to excellence. Thus, it seems reasonable to conclude that only a moderate (or even a small) percentage of those capable of creating products of excellence actually manage to do so. In any case, the road to excellence does not necessarily emerge from extraordinary cerebral gifts, but rather from good management of sufficient cognitive resources.

Finally, in the field of excellence, like in any other, technological resources themselves are not as important as how they are used. Thus, technology in general and the Internet in particular should be seen as a means to an end rather than as an end in and of themselves.

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