Research Trends

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Children of the (scientific) revolution: A bibliometric perspective on Kuhnian paradigm shifts

Thomas Jones
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Section 1: The Value of Bibliometrics

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Useful links:

Global Positioning System (GPS)
www.gps.gov

Black Hole Encyclopedia
hubblesite.org/explore_astronomy/black_holes/encyclopedia.html

In 1962, Thomas Kuhn, a physicist turned philosopher and historian of science, published the landmark book "The Structure of Scientific Revolutions"[1]. At the time, the dominant view held that scientific progress is a continuous process of accumulating new facts and devising novel theories to explain them.

Kuhn argued for a radically discontinuous alternative in which periods of normal science when new knowledge is generated and integrated into existing theories are periodically interrupted by periods of revolutionary science. During revolutionary phases, new facts emerge that do not fit into the existing scientific framework, leading to a revision of fundamental scientific concepts and a replacement of the old framework or paradigm with a new one that is typically incompatible with what went before. The Kuhnian idea of paradigm shifts soon entered popular use, and a number of paradigm shifts have been identified by Kuhn and others.

Yet are paradigm shifts genuinely new beginnings, changing the landscape of science? In this article we look at one of the most famous paradigm shifts in science and ask: what can bibliometrics tell us about whether the paradigm shift has influenced the scientific landscape?

Newton, Einstein and a mysterious attraction

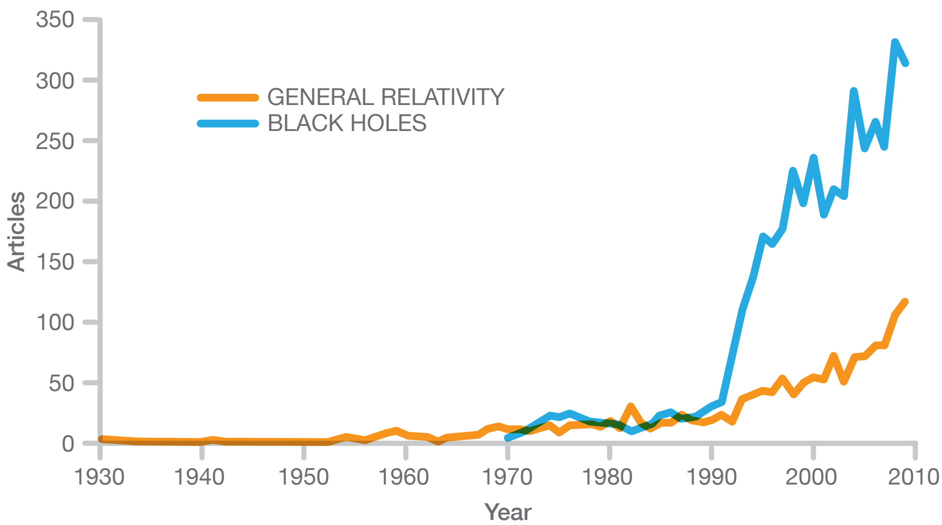
Sir Isaac Newton, in his law of universal gravitation, defined gravity as a force attracting one object to another, the strength of which depended on the masses of the objects and the distance separating them. Newton's law was widely lauded as it explained many, if not quite all, observable gravity-related phenomena.

All this was to change in 1915 over 200 years after Newton published his groundbreaking work when Albert Einstein published his theory of general relativity. The theory proposed that gravity is not a force but the result of curvature in spacetime caused by objects that have mass. Einstein, in short, redefined gravity a fundamental physical phenomenon by reference to a new set of concepts, fitting Kuhn's description of a paradigm shift.

Not if, but when

For many years general relativity was a curiosity rather than a key feature of mainstream physics. By the middle of the 20th century new methods had made the dense mathematics of general relativity more accessible, and the theory began to make an impression on the scientific community. A search in the Scopus database confirms that the number of articles published in scientific journals associated with the keyword "general relativity" began to increase rapidly during the 1960s, and the strong growth trend continues to the present day (see Figure 1).

Figure 1 – Numbers of scientific articles associated with the keywords "general relativity" and "black hole/black holes" published each year in Physical Review journals. Source: Scopus.



The paradigm shift of general relativity was also responsible for a number of scientific new beginnings. Take the concept of black holes stellar bodies so massive that even light cannot escape their gravitational clutches which can be traced to the writings of Cavendish and LaPlace in the 18th century[2]. For many years black holes received little research attention, in part because they were so puzzling. According to Newton, gravity acts between two bodies that have mass but light has no mass, so how can light be pulled towards a black hole?

With gravity redefined under general relativity, interest in black holes underwent a rebirth. A Scopus search shows that the number of scientific articles associated with the terms "black hole" or "black holes" started to grow rapidly from 1970 onwards, closely following the burst of interest in general relativity (see Figure 1). Many of the papers that defined black hole research in the early days continue to be highly cited 40 years later for example, Christodoulou's 1970 paper "Reversible and irreversible transformations in black-hole physics" was cited 62 times between 2005 and 2009 (Source: Scopus).

General relativity is also shaping the scientific landscape in a more subtle and far-reaching way. The Global Positioning System (GPS) uses extremely accurate clocks in satellites to provide precise location data anywhere on Earth. General relativity tells us that time, space and gravity are linked, so that clocks orbiting the Earth at high speed in a low-gravity environment experience time differently than clocks on Earth, causing inaccuracies in GPS. Fortunately, general relativity theory provides the means of correction, producing location measurements that are accurate to within a meter. A Scopus search shows that the number of documents published each year that are associated with the term "global positioning system" has grown rapidly since the system was established in 1973 (see Figure 2). Furthermore, GPS is an enabling technology that is driving research in a huge range of subject areas – simply searching for the keyword "Global Positioning System" in Scopus returns scientific articles on topics that range from human behavior to plate tectonics, and epidemiology to meteorology (Source: Scopus).

Scientific revolution

The emergence of general relativity was a true scientific paradigm shift, in which the long-respected laws of Newtonian physics were replaced with a new set of concepts. Although general relativity remained a scientific curiosity for many years, searches in the Scopus bibliographic database show how the Einsteinian paradigm eventually became part of mainstream science, and the timescale over which the ripples of this paradigm shift reached related fields, eventually leading to novel research on distantly related topics such as GPS.

Further reading:

1. Kuhn, T.S. (1962) The Structure of Scientific Revolutions. University of Chicago Press.

2. Hawking, S.W., Israel, W. (1987) 300 Years of Gravitation. Cambridge University Press.

Figure 2 – Number of scientific articles associated with the keyword "global positioning system" published each year across the range of scientific journals. Source: Scopus.