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Top-Down Research, Generalists, and Google Scholar: Does Google Scholar Facilitate Breakthrough Research?

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Abstract

Researchers long ago demonstrated that top-down, inference-based approaches to research have comfortably co-existed with more traditional bottom-up, hypotheses-driven research. Yet most faculty omit any mention of top-down approaches in direct instruction or training of students, despite these approaches being both relatively common, occasionally necessary, and considerably more efficient than traditional bottom-up research. The growing sophistication of search engine algorithms, like those used by Google Scholar, makes possible highly efficient, inter-disciplinary top-down research. This article explores both the existence and operation of top-down approaches to research in the sciences and the ways in which Google Scholar could work with top-down research strategies to transform collaboration and inter-disciplinary research, particularly in the sciences.

Keywords

Abduction, Reverse Entailment, Top-Down Research, Interdisciplinary Research, Google Scholar

Subject Areas: Gastroenterology & Hepatology, Infectious Diseases, Information Science, Internal Medicine, Library, Intelligence and Philology

1. Introduction

In academia, the intellectual carpet-bagger is about as welcome as the men who inspired that word, American Northerners who traipsed below the Mason-Dixon Line and tried to gain political footholds in Southern states still smarting from the havoc wreaked by the Civil War. And yet, my life as an intellectual carpet-bagger has provided me with some particularly useful insights, occasionally in bringing the methodologies from one discip-

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line into another where I happened to alight. Fourteen years ago, I began to edge crab-wise into the health sciences from the humanities, equipped with eighteen years of experience in medical copywriting for Big Pharma and an understanding of the cognitive underpinnings of reading and writing that proved relevant to teaching researchers and clinicians in medicine. Within a decade, I had taught faculty in virtually every specialization, from neurosurgery and gastroenterology to genetics and veterinary pathology. Then, two years ago, something peculiar happened. I began formulating novel hypotheses, writing papers, and getting them published in rather good medical journals. No one quite understands how someone with a non-science doctorate can suddenly begin spouting off about the extracellular matrix and its relationship to rare genetic disorders. More puzzling still, my manuscripts were somehow passing the gauntlet of peer review in an era where peer reviewers seem to have become less and less forgiving.

But I have a Rosetta Stone, of sorts. It's called Google Scholar. Using it, I can dramatically decrease barriers between disciplines. At the same time, I can also leverage a top-down model for creating and validating innovative hypotheses that reflects the processes involved in breakthrough research.

2. The Myth of Bottom-Up Research

I started actively teaching my graduate students about the difference between top-down and bottom-up research long before I began practicing it quite so literally. In contrast to academia, in advertising and public relations, the lead-time from receiving a brief to making a deadline can be measured in hours, not weeks or months. To survive, copywriters work from a brief backward, beginning with the result the client wants to achieve and making raids into whatever scientific literature supports the goal. However, as graduate students, we're taught the academic research looks a lot like the sedimentary layers we see preserved in sandstone. We accrete facts in layers, gradually accumulating evidence until we prove a hypothesis. Even faculty members who head basic science labs and clinicians argue that they're gathering facts, emerging at the end of years of murine data or clinical trials of novel therapies with new data that expands our current understanding of a phenomenon or treatment.

Of course, since at least Fleck's *The Genesis and Development of a Scientific Fact*, skeptics have pointed to the means by which paradigms give rise to the "evidence" that demonstrates their validity [1]. Fleck's work gained currency and visibility in the English-speaking world after Kuhn established the way in which so-called "normal science" proceeds [2]. The dominant paradigm establishes what we accrete, with researchers discarding anomalies that fail to conform to expectations fostered by the paradigm. Only when the anomalies outnumber the confirmations do researchers begin to consider alternative paradigms [2].

From experience, I learned that, if researchers in the health professions had even heard of Kuhn, they nearly inevitably dismissed his notion of the progress of normal science and its paradigms as the province of the physical sciences. The progression from Newtonian physics to the post-Machian paradigm is, after all, easy to grasp, particularly since astronomy and physics have models that appear egregiously dated, once one has the right sort of technology to get better data that undermines the old paradigm. In medicine, they argued with me, we have no such paradigms, once medicine got over that business of the body having humors and bleeding patients for whatever ailed them.

Of course, medicine has its paradigms, and Robin Warren and Barry Marshall fell spectacularly afoul of them—from our point of view, conveniently recently. Robin Warren, a pathologist then in Perth, noticed in 1979 that he found the same bacterium in biopsies of tissue taken from patients with a variety of stomach complaints, all involving inflammation. Marshall had the temerity to present a paper at a 1983 meeting of infectious disease specialists, arguing that the pathogen *H. pylori* caused peptic ulcers. That same year, a social scientist had published a scholarly paper that folded neatly into the then-dominant paradigm in gastroenterology regarding peptic ulcers. They developed, she wrote, "from the frustration associated with the wish to receive love" [3].

Despite the fact that German scientists had first identified the bacterium later known as *H. pylori* under a microscope in 1875 [4]. Marshall's findings were decisively derided. The paradigm for decades held that peptic ulcers were caused by a combination of stress and spicy foods [5]. Moreover, the bacterium was anaerobic, notoriously difficult to culture and tended to die off quickly outside the highly acidic environment of the stomach, making its identification problematic [6]. Gastroenterologist and infectious disease specialists set out to disprove this challenge to the dominant paradigm… and failed. Moreover, Marshall and Warren had two other items weighing in their favor. First, the pair had a damned good story, involving Marshall's downing a bacterial cock-

tail containing, by his estimate, a billion of the suspect bacteria, giving himself a peptic ulcer, and curing it with antibiotics [3]. Second, gastroenterologists had, by the seventies, begun using endoscopes that enabled them to examine and culture living gastric tissue [5]. The result was the diagnosis and treatment of *H. pylori* that has become the standard of practice in gastroenterology [7]. Yet, for their pains, the pair was excoriated for years by nearly everyone in medicine, with entire laboratories hard at work on disproving the existence of anything resembling *H. pylori* in the presence of peptic ulcers [3]. In 1994, the U.S. National Institutes of Health finally concurred with Marshall and Warren's findings. In 2005, the pair received the Nobel Prize in medicine.

Still, one thing is missing in this moment when we get to observe Kuhn's paradigm shift in action. We don't observe the moment when Warren's biopsies and the peculiar bacterium they contained met a then-thirty-two year-old resident who kept encountering inflammation in the stomachs of patients with chronic gastritis. At that moment, the pair made a top-down leap, framing a hypothesis that peptic ulcers might be caused by this bacterium that consistently appeared in Marshall's patients' stomachs [6]. From there, they moved to biopsied gastric tissue from patients diagnosed with peptic ulcers [3] and then to the moment when Marshall caused and cured his own peptic ulcer [5]. Ironically, the very gastroenterologists and infectious disease specialists who were so quick to criticize the *H. pylori* hypothesis were themselves performing the same kind of top-down research. However, they were merely pursuing stress as a causal factor in tissue biopsies and randomized controlled trials of antacid therapy, where Marshall and Warren were chasing *H. pylori* as a causal factor with the same methodological tools.

3. The Reality of Top-Down Research

The study of scientific discovery has long been plagued by question of how Marshall and Warren got from the bacterium that kept turning up under Warren's microscope and in the stomachs of Marshall's patients to the notion that this newly-discovered bacterium, *H. pylori*, caused gastritis and stomach ulcers. C.S. Peirce mulled over the ancient problem of logic and scientific discovery and decided that reasoning proceeded from inferences guided by principles [8]. Peirce is a bit murky on exactly how the whole apparatus of arriving at a hypothesis and confirming it actually operates [9]. For example, he claims that hypotheses result from flashes of insight but also that they are the result of what he dubs "abduction," which stems from the making of inferences. Induction, coupled with deduction, then does the donkey-work of verifying the validity of the hypothesis [10]. The problem of how one gets from identifying a peculiar bacterium that keeps cropping up in the guts of patients complaining of dyspepsia to identifying *H. pylori* is compounded by many scientists insisting that proper science cannot proceed unless governed by a hypothesis [11]. Yet, in the earliest stages of scrutinizing this oddly recurrent bacterium, neither Warren nor Marshall had arrived at the hypothesis that it caused peptic ulcers—only that the bacterium had an association with inflammation in the gut. In the same way, John Snow did not yet have a hypothesis about the origins of the cholera epidemic, let alone a working hypothesis about the causes of the disease, until he zeroed in on the pump in London's Broad Street [12].

However, recent scholarship has refined this view of how scientists proceed from observation to what constitutes evidence to hypothesis. Scientists actually work through two modes of discovery that are complementary, not mutually exclusive. In one mode of operation, they accrete evidence supporting dominant hypotheses while also broadening or deepening our understanding within a paradigm. But, in another, less common mode of operation, scientists also work in reverse, going from an effect to gathering evidence for a cause, using the process of inverse entailment [13]. In fact, inference to the best explanation informs the reasoning of not only scientists but also clinicians, jurists, historians, and detectives [14]. In other words, research and discovery have always relied on both bottom-up and top-down approaches.

For some reason, though, the canard has persisted that research is always a bottom-up slog and a top-down approach is an inevitably suspect short-cut. Certainly, this philosophy that science is always bottom-up in the service of a hypothesis [11] accounts for the fierce reactions of researchers who strove to disprove the novel hypotheses about *H. pylori* [3] [5] and the origins of cholera [12]. Moreover, this same aversion to viewing research as ever being top-down persists, even if we allow for this type of reaction stemming from either a misreading of Popper [15] or from the reactions of scholars invested in the dominant paradigm, protecting their reputations by attacking alternative paradigms [2].

This bottom-up view of the progress of the practice of research has three particularly problematic implications. First, graduate students, some faculty, and many researchers tend to believe it and thus pursue bottom-up re-

search exhaustively. Second, this bottom-up approach is notoriously inefficient, sending researchers through lengthy experiments and literature reviews in the service of incrementally nudging the boundaries of our current understandings. Third, and perhaps most important, a strictly bottom-up approach to research limits innovative leaps, like the ones made inferentially by Marshall and Warren or by John Snow and potentially hampers the very progress of science that research is supposed to support.

In fact, scientists themselves tend to undervalue analogic thinking in the role of discovery, to the point where they underrepresent the role it plays even in their own breakthroughs [16]. Perhaps for this reason, they tend to underplay the value of making analogies in the training of their graduate students, who themselves seldom employ analogies in their thinking or research [17]. Strikingly, in this same study, Dunbar noted that researchers consistently underestimated the number of times they had used analogic and inferential thinking in formulating hypotheses [17]. In all likelihood, both highly experienced and productive researchers tend to underestimate the amount of inferential thinking they use in formulating top-down research strategies. This oversight is peculiar, especially given research on innovation across technology, science, and industry, which has consistently demonstrated that breakthroughs occur via analogic thinking—usually where a specialist from one field brings methodologies, evidence, or assumptions to a new domain [18]-[21].

4. Google Scholar Makes More Efficient Top-Down Approaches to Research

Despite students rarely receiving instruction or mentorship on top-down approaches to research, some scientists have readily acknowledged that inferential and hypothesis-driven research comfortably co-exist [22]. Furthermore, some scientists have argued that digital technologies can facilitate new discoveries—even to the point of using evolutionary algorithms to automate the process of selecting and performing experiments [13].

When research works from a top-down approach, researchers rely on multiple strategies. These strategies include inference to the best explanation [14] and heuristics that rely on constraints from domain-general knowledge [23] Top-down approaches also rely on analogies and examples [24], as well as on inverse entailment, where researchers make generalizations based on observing effects to arrive at a series of potential causal mechanisms which they can then test [13] [25]. Still other top-down approaches include a counterpart of the structured programming used in computer science, where a series of functional analyses examine effects and treat potential causation as a series of black boxes, using regression to eventually reduce the nested black boxes to a sufficiently simple black box that points to a potential causal mechanism [26].

However, two top-down approaches are particularly relevant to efficient searching using computer-based algorithms, like those employed by Google Scholar. In the 1950s, Herbert Simon proposed using research methods that use bounded rationality or a means of processing information that relies on what Simon dubbed "satisficing" [27]. Satisficing, a blend of sufficing and satisfying, is a Scottish word Simon uses to characterize algorithms that successfully deal with conditions of limited time, knowledge, or computation capacities. His conception of satisficing involves choosing several alternatives that satisfy aspirations, instead of surveying all possible alternatives, estimating probabilities and utilities for all possible outcomes associated with each alternatives, and choosing the alternative that scores highest in terms of calculations of expected utilities [28]. Simon's satisficing enables researchers to employ Probabilistic Mental Models (PMMs) that use limited knowledge to make inferences rapidly [29]. Unlike Johnson-Laird's mental models based on syllogisms and deductive inferences [30], PMMs take the best algorithm that uses simple recognition of an object and then searches for the values of the best cue, a strategy that is currently best approximated in digital searching for documents by Google Scholar, where PMM-like algorithms far outperform those used by other search engines [31] [32].

In one study comparing the academic databases Scopus and Web of Science with Google Scholar, Google Scholar generated the most results and the greatest number of unique items. These findings are particularly striking, given that researchers conducted this study only two years after Google Scholar's debut [33] when fewer articles were available online than are today. Moreover, since its debut in 2004, Google Scholar's algorithms have gained in effectiveness and redressed many of the shortcomings researchers found in its beta release [31]. Initially, Google Scholar's beta version often displayed problems in filtering keywords [34], in addition to biases toward English language entries [31]. In contrast, by 2011 the search engine not only correlated reliably with the Thomson Institute for Scientific Information (ISI) in hits on high-impact factor journals but even yielded hits on relevant articles in four times as many journals as an ISI search with the same parameters [35]. Perhaps most significantly, the Hodge and Lacasse study [35] offset earlier criticisms of Google Scholar's utility being markedly higher for researchers in the physical, biological and health sciences over the social and human

sciences [36]. However, as critics of Google Scholar have rightly noted, using this particular search engine is hardly a short-cut to instantly assembling a research paper that might pass muster in an undergraduate course, let alone in a peer-reviewed journal [37] [38]. Ultimately, Google Scholar is a valuable tool in the hands of researchers who already possess sufficient domain-specific knowledge that enables them to know (1) where to seek substantiating evidence for inferences, (2) how to measure the value of the articles and documents its searches produce, and (3) how to place this knowledge within a network to buttress the validity of their claims [39] [40].[1]

Ultimately, top-down searches using algorithms yield the kind of results that would satisfy Popper's criteria for hypotheses [15] only when the person conducting the search has sufficient domain-specific knowledge to distinguish useful from non-useful hits during a search. Additionally, the researcher needs to understand the nomenclature, assumptions, and methods specific to the field. In other words, top-down searching using Google Scholar isn't quite the short-cut to producing a novel, defensible hypothesis that it might first appear. One has to spend a significant amount of time immersed in discipline-specific knowledge, as I did in my years in teaching in the health professions, before either a bottom-up or top-down approach to research becomes tenable.

5. How Might Google Scholar Change the Landscape of Research?

Domain-specific knowledge plays a powerful role in enabling researchers to discriminate between rival explanations and efficiently pursue plausible explanations [23]. As a consequence, the top-down approach to research works most effectively under two conditions. First and most commonly, experts with both broad and deep knowledge of a single domain tend to formulate novel inferences and pursue top-down research strategies. Second, generalists acquire sufficient knowledge of multiple domains, enabling them to spot meaningful patterns in data or to see potential hypotheses in incidental findings in data that labs would otherwise discard. Significantly, in his study of scientists at work, Dunbar found that 40% - 60% of findings generated in laboratories were unexpected. Moreover, contrary to the popular view of science as being relentlessly hypothesis-driven and bottom-up, nearly all unexpected findings received considerable scrutiny by researchers who encountered them. Of this surprisingly high proportion of incidental or unexpected findings, Dunbar discovered researchers attributed only 30% to methodological error and 8% to simple mistakes, with the remainder seen as evidence of either unknown origins (54%) or a novel mechanism (8%) [17]. Moreover, domain-specific knowledge made top-down inferences more efficient via priming [16] and the use of heuristics in determining which explanations might prove most fruitful in accounting for novel mechanisms [23].

Prior to the advent of sophisticated search engines like Google Scholar, only specialists with sufficiently broad or deep domain knowledge could feasibly and efficiently pursue the causal mechanisms behind incidental findings. Furthermore, even top-down research could take decades, during which researchers strained to identify patterns in incidental findings or light on the probable causes for unexpected results. For example, in the discovery of *H. pylori*, Warren first noticed a new bacterium in biopsies in 1979 [5], but five years elapsed before Marshall resorted to using himself as a human guinea pig in drinking *H. pylori* in 1984 [3]. Moreover, the pair submitted their hypothesis to conferences with skeptical audiences and published papers in journals with only limited audiences before finally gaining a wide readership with a study that appeared in *The Lancet* [7], fully eight years after Warren first spotted the bacterium. Additionally, the mechanism by which *H. pylori* survived in such an extremely acidic environment would remain only vaguely explained for another nine years [6].

Today, the landscape is dramatically different, altered by relaxation of the Ingelfinger rule embargo on publishing preliminary data [42], augmented by the sharing of information facilitated not just by online publications but also by the world-wide web, initially designed to enable researchers to create a network of publications and citations [43]. As a result, Google Scholar and other algorithm-driven search engines that succeed it can make possible three particularly key developments in research. First, researchers with minimal investment in dominant paradigms, like Marshall, can leverage findings from other fields, creating the network of citations that demonstrate the validity of researchers' claims [40] and also make peer reviewers more receptive to novel hypotheses. Second, Google Scholar enables a researcher who generates a novel hypothesis from incidental findings or trends in meta-data to enlist collaborators from multiple disciplines or to even independently conduct genuinely interdisciplinary research by delving into publications spanning multiple fields. In academia, this development is

[1]The role played by citations in creating powerful networks of allies and establishing the validity of hypotheses is well-trammeled territory. First explored by Latour and Woolgar [40] and subsequently comprehensively by Latour [39] and in Woolgar's *Science, The Very Idea* [41], not to mention in an entire sub-field of sociology, the Study of Scientific Knowledge (SSK).

particularly consequential, as disciplines tend to exist in intensely siloed conditions, where divisions and subdivisions between disciplines persist even among library staff serving a common community [44]. Despite the creation of tools like the world-wide web, aimed at creating shared resources for scholars, academia has continued its trend in maintaining disciplinary boundaries, even in the face of initiatives like the Human Genome Project that required teams of specialists from many disciplines to work together integratively [44] [45]. As Leshner noted, these boundaries persist largely due to processes involved in grant reviews and in tenure and promotion [45]. However, the process of publishing peer-reviewed research, particularly in high-impact factor journals, can serve to credential researchers [46], enabling them to leverage inter-disciplinary research in applying for grants and positions in disciplines far from the fields in which they originally trained. Third and finally, generalists can finally realize their full utility, which lies in recognizing mechanisms, trends, and developments that fall into the interstices between specializations, as well as the neglected topics glossed over even by subspecializations [47]. Moreover, generalists have the ability to make connections across multiple disciplines, leveraging analogies from other fields to arrive at inferences about common mechanisms. Generalists can also work with more readily and easily with cross-functional teams of researchers drawn from multiple specializations, an ability reflected in the significant value assigned to generalist CEOs compared with CEOs with experience in only a single field or industry [48]. Unlike business and industry, the sciences and academia generally have been slow to recognize and reward the potential value generalists bring to research—a tendency tools like Google Scholar can help counter.

In my own classrooms, where I teach post-doctoral students, fellows, and faculty in the health professions, I have watched students move with increasing assurance between disciplines, readily arguing over the underlying basic, translational, and clinical mechanisms that overlap the fields they routinely bring into my required course on scholarly writing and publishing. Yet, whenever I mention the utility of Google Scholar as a means to facilitating more efficient research, virtually every student in my course has assumed I was merely referring to a feature in Google Scholar that enables researchers to import citations directly into reference-formatting software like EndNote, RefMan or RefWorks. Nearly inevitably, they appear flabbergasted when I link Google Scholar and top-down research strategies, mentioning that I have published articles spanning ten disciplines, each manuscript researched and written in a matter of days.[2]

Ultimately, using tools like Google Scholar to openly facilitate inter-disciplinary, top-down research can also result in better means of collaboration in writing up research. Until comparatively recently, many scientific articles were a pastiche of contributions from collaborators with varying specializations, composed in discrete chunks and passed between writers like a baton in a relay race. The result was often uneven, with considerable variations in rhetorical approach, syntax and diction. Now, a single author can facilitate most of the production, doing much of the writing by leveraging publications found through searches using Google Scholar. The same author can then sketch out gaps that require domain-specific knowledge only other collaborators possess. In addition, the lead or senior author can even assign tasks to a team of collaborators from a range of disciplines which she or he assembles, down to forwarding potentially useful references or even entire reference libraries to other contributors.

6. Conclusion

From all the evidence, top-down research strategies should have ceased to be a dark secret or the province only of seasoned researchers. If Google Scholar serves merely to make this strategy more common and accessible to researchers, the search engine will already have performed no small service in transforming academia. But the search engine could also help break down barrier between fields and make inter-disciplinary research an everyday occurrence. And, perhaps, Google Scholar could even make intellectual carpet-bagging comprehensible and even desirable in academia.

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