Breakthrough Knowledge Synthesis in the Age of Google

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Using today's web-based interactive tools such as Google's ubiquitous search engine and online databases, students, educators, practitioners, research scientists and inventors have an unprecedented opportunity to discover breakthrough knowledge by synthesizing current and prior knowledge available online

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1. Introduction

Great minds throughout human history have endeavored to understand the nature of knowledge, which forms the subject of the branch of philosophy known as epistemology, a word that translates to understanding [1]. In his dialogue Theaetetus, written around 369 BC, the philosopher Plato originated a definition of knowledge as justified true belief [2]. Despite criticism by epistemologists and other philosophers, such as Gettier in 1963 [3], Plato's contribution to the definition of knowledge has endured to this day. But how is new knowledge created, especially in other branches and areas of philosophy, such as logic, education, and science? Sir Isaac Newton wrote in 1678, "If I have seen further it is by standing on ye shoulders of giants" [4]. Newton's statement implies that he discovered new knowledge by building upon prior knowledge discovered by others. More recently, researchers examining more than 28 million studies and over 5 million patents discovered that breakthroughs in almost all fields of knowledge are more likely to occur as large amounts of prior knowledge are mixed with current, extant knowledge, confirming Newton's observation [5].

The definition of breakthrough means to overcome a barrier, and breakthrough knowledge implies overcoming barriers to advance knowledge. One barrier to knowledge advancement throughout history has been a powerful status quo which resists novel ideas. For example, while conducting his scientific research at the University of Padua, Italy, Galileo Galilei complained in a letter to scientist Johannes Kepler in 1610 that "these philosophers shut their eyes to the light of truth" [6]. The philosopher Thomas Kuhn [7] later described how most advances in scientific knowledge involve incremental changes within the conventional paradigm. Kuhn further noted how scientific revolutions occur periodically as new knowledge breaks through conventional barriers and causes a disruptive shift in the reigning paradigm. Another historical barrier to the advancement of knowledge occurred throughout Europe in the Middle Ages, when recorded information was owned exclusively by elite sectors of society, usually the clergy and members of academia. As knowledge spread with the advent of the printing press, the power of the Catholic Church was reformed, and the printing press had an influential effect on the Renaissance and the Scientific Revolution [8]. Since then, modern society has witnessed a relentless movement toward the democratization of the public's access to knowledge, especially in the age of digital technology.

Using today's web-based interactive tools such as Google's ubiquitous search engine and online databases, students, educators, practitioners, research scientists and inventors have an unprecedented opportunity to discover breakthrough knowledge by synthesizing current and prior knowledge available online. As academic libraries have digitized much of their content, no longer must students, practitioners, and researchers descend into the dark and dusty basements of institutional buildings seeking microfiches of archived literature. And yet, despite advances in accessing information online, a coming revolution in breakthrough knowledge appears to lie beyond the horizon. Students seeking new knowledge may feel hopelessly overwhelmed as they are bombarded with an overload of redundant online information [9], much of it of questionable veracity. In a quest to discover breakthroughs, research scientists may lack the advantage of leveraging online information search tools [5], inhibiting their capacity to step outside their disciplines and generate innovative, novel theories with the potential to produce a revolutionary paradigm shift in scientific concepts and practices [7].

2. Synthesis

The traditional use of the word art means skill [10]. The art or skill of knowledge synthesis relies on the ability to retrieve information from peer-reviewed studies and form an academic literature review, which provides more than an annotated bibliography of summaries [11]. A synthesis, the assembly of parts into a new whole, organizes and interprets the concepts, connections, controversies and constraints of a body of literature, filling in gaps and generating new insights, perspectives, directions and novel explanations about the research topic.

Other terms for knowledge synthesis include research synthesis, evidence synthesis, and scientific synthesis. Syntheses can integrate current knowledge to inform policy and best practices, as in systematic reviews and meta-analyses, or syntheses can create new knowledge by combining evidence from a wide variety of sources [12]. The latter type of synthesis for new knowledge generation at the source of the flow of scientific information, from theory to practice, is the topic of this research. The term emerging synthesis has been used to describe the ongoing evolution of newer types of synthesis method in which a wide diversity of quantitative and qualitative findings, data, and research designs are combined together to contribute new knowledge and theory to a research area [13].

Explanatory theories that explain causes and effects are qualitatively different from descriptive theories that categorize, organize, and describe phenomena [14]. Hjørland's domain-analysis is an example of a descriptive theory used in library science to organize knowledge according to the specific contents of information within a knowledge domain [15]. I propose that differences between explanatory and descriptive theories are similar to differences between explanatory and descriptive knowledge syntheses. For example, in addition to its use in systematic reviews and meta-analyses, descriptive knowledge syntheses categorize and organize information in taxonomies, ontologies, encyclopedias, databases, library systems, and complex networks. Furthermore, data mining methods have been used to predict new information in complex networks, such as the prediction of paired protein interactions in a protein database, and the prediction of interactions within social networks [16]. However, these methods have limitations. Interactive predictions in social networks, based on observed structural patterns, were shown to have a low rate of correctness [17]. In addition, the method for predicting protein interactions, based on classification of interaction types, does not explain how predicted interactions function, which must be determined with follow-up studies [18], On the other hand, explanatory knowledge syntheses logically combine concepts to infer new explanatory theories and hypotheses which may lead more directly to new explanatory knowledge.

3. Synthesis in Education

Knowledge synthesis is not only an important theoretical concept in the philosophy of knowledge; it plays a role in the philosophy of science, where it also serves as a practical research method, and it is a valued concept as well in the philosophy of education. Teaching the skills necessary for researching and writing knowledge syntheses is an important educational objective. The ability to synthesize material begins as an academic skill developed in secondary school and post-secondary school [19]. Bloom's original 1956 taxonomy of educational objectives included synthesis, the ability to assemble parts into a new whole, along with other educational objectives, such as knowledge, comprehension, application, analysis, and evaluation [20]. A revised version of Bloom's taxonomy, **Figure 1**, advanced synthesis to the highest educational level as part of Creating [21].

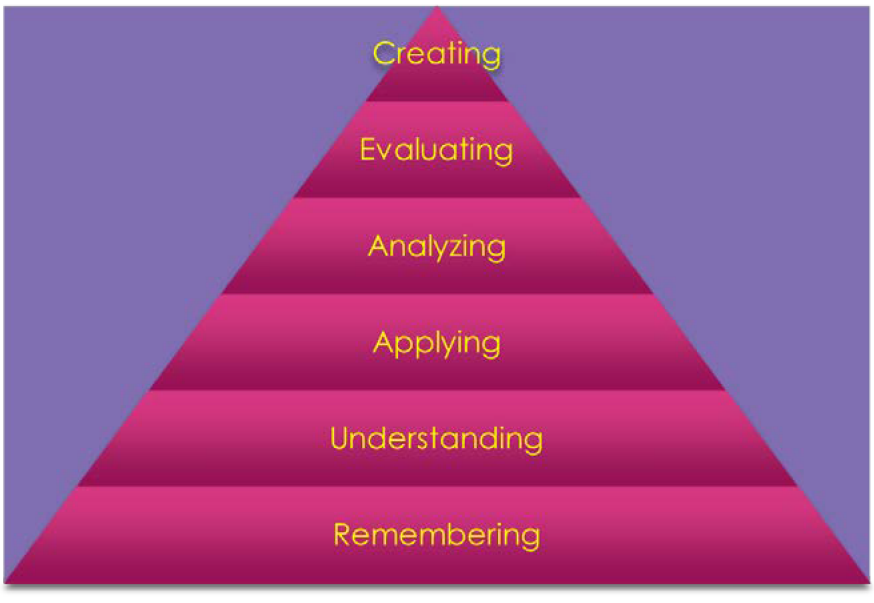

Figure 1. Bloom's taxonomy. Based on Forehand [21].

Training in synthesis skills should be acquired early in a researcher's career [22]. Today's evidence-based medicine is increasing the need for biomedical students to acquire research skills in information retrieval, critical judgment, statistical analysis, and writing [23]. Writing with rigorous analysis and logic is a critical professional skill required by most businesses, industry [24], and government agencies [25]. The National Commission on Writing in America's Schools and Colleges recommends that teachers encourage students to view writing as an enjoyable method for learning and discovery [26]—synthesizing new knowledge is a writing skill that can fulfill that recommendation by stimulating students with the excitement of exploration and discovery, leading to potential breakthrough knowledge. However, methods of synthesis writing must be developed to help students acquire proficiency in the skills of selecting, organizing, and associating information.

Recently, a method improved synthesis writing skills in students by employing note taking for information selection, and providing students with a graphic matrix organizer that presented information side-by-side to more easily draw associations between texts [27]. This method of teaching synthesis writing could be combined with use of web-based interactive tools in the classroom, which have been shown to enhance student engagement and improve learning experiences [28]. For example, web search engines could be used to teach students how to search, select, and synthesize online text sources in subject areas of interest to them. In addition to advancing keyboard, language and writing skills, students can practice skills to conduct online research which include forming a research question, locating online information, evaluating the information for selection, synthesizing the selected information, and communicating findings [29].

Another observation, relevant to the creative nature of synthesis in education, is the influential role knowledge synthesis plays in the development of the creative arts and humanities. For example, I propose that a composer synthesizes music out of musical components such as rhythm, timbre, pitch, and harmony. A painter synthesizes a painting out of form, texture, perspective, and color. A poet synthesizes a poem out of language, metaphor, and emotion. Artists often synthesize their style from the styles of the artistic giants who influenced them. Languages themselves are synthesized from other languages, social scientists such as psychologists and economists synthesize their work from the work of their predecessors (e.g., Freud and Marx), and so on. All fields in the arts and humanities have the potential to benefit from the knowledge synthesis methods described in this research.

4. Synthesizing an Explanatory Theory

Psychologist Kurt Lewin proclaimed, "There is nothing so practical as a good theory" [30]. This research's method of knowledge synthesis borrows heavily from theoretical research methods such as grounded theory. Glaser and Strauss developed the grounded theory method to bring more rigor to qualitative research [31], although the methodological principles of grounded theory are also applicable to quantitative research [32]. The researcher's overarching aim in grounded theory is to begin an investigation with a clean slate and inductively construct a new theory through an iterative process of comparative data analysis. With a new theory in hand, the researcher can encourage the development of hypotheses to experimentally test concepts deducted from the theory. Eventually, systematic reviews and meta-analyses can critically assess results of experiments and clinical trials testing the concepts. Interestingly, Ioannidis [33] suggested that the number of systematic reviews of clinical trials may be currently higher than the number of clinical trials, implying a greater need for theory synthesis at the source in the flow of new scientific information. Of relevance, the number of physician-scientists has also been on the decline over the past several decades, further highlighting the need to increase physician medical education in scientific thinking and biomedical research [34], including a need for education in knowledge synthesis and theory development.

Researchers most often use grounded theory as a method to analyze, compare, and combine concepts from original data, but Wolfswinkel et al. proposed that grounded theory may also be used to conduct a rigorous literature review in which concepts from published research findings themselves are the data [35]. Reviewing literature in this manner is particularly useful for synthesizing new knowledge from current knowledge—similar to thematic synthesis [36], a qualitative method that combines thematic analysis with meta-ethnography across multiple studies. An important difference is that the method proposed by Wolfswinkel et al. is a mixed method that combines both qualitative and quantitative research.

The following is an example of how I used a grounded theory approach to conduct a web-based synthesis in the field of epidemiology. I was interested in exploring online research literature investigating the association of phosphate toxicity with cancer [37]. The literature was reviewed using keyword searches in Google, Google Scholar, and other scholarly online databases, and all relevant studies associating phosphorus, tumorigenesis, cancer, etc. were identified. In addition

to searching with keywords, I searched references cited in studies, which is known as citation analysis; a very useful method for evaluating a study's impact in a research area [38]. For example, The Hallmarks of Cancer [39] is an influential study often cited by other studies in a literature review of cancer research.

Included in my synthesis were studies selected from the fields of basic research, clinical research, and epidemiological research; the designs of the selected studies included case studies, cohort studies, laboratory animal experiments, in vitro studies, systematic reviews and meta-analyses. My investigation followed the evidence without boundaries, and my final synthesis was written in the form of a narrative review. Although many speculations, hypotheses, and explanatory theories were proposed by authors of the studies selected for my synthesis, I analyzed only concepts from the objective findings of the selected studies in order to foster a new grounded theory. The rigorous evidence-based grounded theory method helped assure the high internal validity of the synthesis, i.e., the analyzed concepts were based on trustworthy peer-reviewed findings rather than speculation. As concepts from the reviewed literature were analyzed and compared, certain themes began to emerge from the data which were eventually linked together into a cohesive theory that explained how phosphate toxicity from dysregulated phosphorus metabolism stimulated cancer cell growth. Interestingly, this inferred knowledge challenged several of the hypotheses proposed in The Hallmarks of Cancer. For example, evidence from my synthesis supported the concept that cancer cell growth is dependent on exogenous growth-rate factors, challenging the concept that cancer cells independently stimulate themselves to grow autonomously.

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