Empowering Accelerated Personal, Professional and Scholarly Discovery Among Information Seekers: An Educational Vision

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Editors' note: Dr. Harmon died on February 17, 2013, before this article came to press. Dr. Harmon contributed extensively to the LIS field through his long career that included 43 years on the faculty at the University of Texas at Austin. The editors' introduction to this issue of JELIS (Volume 54, Number 2) includes an extended description of Dr. Harmon's academic life that was shared with us by the University of Texas at Austin School of Information. We are saddened by Dr. Harmon's death and deeply honored to be publishing this paper in the pages of JELIS.—*Michelle Kazmer & Kathy Burnett*

The term discovery applies herein to the successful outcome of inquiry in which a significant personal, professional or scholarly breakthrough or insight occurs, and which is individually or socially acknowledged as a key contribution to knowledge. Since discoveries culminate at fixed points in time, discoveries can serve as an outcome metric for both inquirers and the information professionals who support inquiry. First, the primacy of information seeking behavior is explored, particularly its key role in guiding the development of various kinds of supportive information architectures and services. Second, three models of the discovery process are presented, with suggested ways to accelerate discovery via each model. Last, a case is made for developing a strategic vision for LIS and iSchool education. This educational vision involves augmenting information behavior theory with a generalized art and science of search, research and accelerated discovery, and the development of systems and technologies to prompt discovery.

Keywords: discovery, discovery content analysis, information seeking, information behavior, search, research, information studies education

Introduction

The term discovery has been defined in numerous ways throughout recorded history and has many alternative meanings. Each discovery is highly context and time dependent. Discovery can apply to various contexts and circumstances: to the learning and education process; to geographical discovery of different regions; to the cosmological discovery of hitherto unobserved stars and planets; to discovery of new microorganisms; to technological or social innovations; to the discovery of mathematical and scientific equations; to social science laws and trends; and to various kinds of personal and subjective discoveries. Alternatively, old phenomena might be seen in a new light or novel way, thereby rendering previous models, theories or paradigms as obsolete or as special cases of newer, more abstract perspectives.

Because the concept of discovery and its variations can be applied widely to all information seekers and across multiple domains of knowledge, the concept

of discovery can provide one key basis for the development of information systems or information studies programs and their curriculum offerings. As professional practitioners, whether in libraries, archives, museums or other organizations or environments, graduates of iSchool and LIS programs will be on the front lines of facilitating their clientele's accelerated personal, professional, or scholarly discovery.

Accordingly, this paper explores and makes a case for developing a targeted educational initiative for LIS and iSchools—that of educating their students and encouraging their alumni to promote accelerated discovery throughout the arts, sciences, professions and the general public. Within information science and professionalism, the concept of discovery potentially provides an integrative purpose and clear *outcome metric* for information seekers—the successful culmination of inquiry. Discovery acceleration heuristics can also guide the development and operation of numerous, supportive information infrastructures, including ubiquitous information environments. The mission of accelerated discovery can also serve to bridge longstanding divisions or distinctions within the information professions (e.g., between system-centric institutional and computer system orientations, between user-centric information seeking orientations, between theory and practice advocates, and between orientations that focus on the fields of digitization, libraries, archives, museums, or intelligence gathering).

The paper first explores the benefits of creating a body of information behavior theory to guide the development of future information infrastructures, particularly those capable of supporting accelerated discovery. Second, three models of scientific discovery, based on this author's research, are briefly discussed (a chronological timeline model, an information acquisition and ordering model, and a systems ontology model). A discussion of possible approaches to accelerating discovery follows the presentation of each discovery model. Although examples of the nature of discovery and its possible acceleration are drawn from mathematics and science, discovery concepts can be applied in a very broad sense to include personal, professional, scholarly, or social discoveries. In each type of discovery, a significant insight is individually or collectively achieved, recognized as significant, and acknowledged as such over time. Last, the paper concludes with a vision of educational endeavor based primarily on creating a comprehensive art and science of search, research, and accelerated discovery.

The Priority of Information Behavior Theory

Any given discovery is usually acknowledged as an important scientific, social, or individual outcome metric—one marked by a culminating event at a given time point. As such, discovery might be regarded as one potential metric within information professionalism that subsumes or complements such existing outcome metrics as user satisfaction, optimal information retrieval relevance and recall, and usability. Accordingly, the concept of discovery and its acceleration might well be further incorporated into information behavior (information need and use) studies to help build a viable body of theory in that area, one strong enough to provide clear, specific parameters for system development, professional practice, educational efforts, and the broader research realm.

A broad sweep of state-of-art studies of information behavior topics included in the *Annual Review of Information Science and Technology* from Volume 1 (1966) to Volume 45 (2011—the last volume) sheds light on the status and thrust of information behavior over recent decades. Menzel (1966) discusses the then incipient nature of "Information Needs and Uses in Science and Technology," noting that, despite the development of unique methodologies, user studies did not have much

impact on research and practice in information professionalism. Subsequent *Annual Review* user study chapter authors echoed Menzel's observations throughout the 1960s and 1970s, calling for more precise conceptual definitions, more eclectic methodology, enlarged scope coverage to different settings and groups, broader applicability of findings beyond local settings, greater rigor, and stronger theory development. These reviewers noted weak connections between user behavior findings and the typically trial-and-error system development efforts deployed during those decades. Dervin and Nilan (1986) observed, however, that there had been greater progress through holistic analyses of behavioral processes, such as active user construction of concepts, and they noted the evolution of three new analytical approaches: user value impact, sense-making, and dealing with anomalous states of knowledge. Moreover, Dervin and Nilan noted the need to find new ways to link user studies to system development, beyond simplistic one-to-one mappings. In their recent *Annual Review* coverage of information behavior, Fisher and Julien (2009) conclude that information behavior research has finally developed into a core area of study, by virtue of its more interdisciplinary nature, greater conceptual and methodological rigor, development of new theories, and its focus on both web-based inquiry and information seeking in context. Case (2008) provides a masterful synthesis of over five decades of information behavior research, in which he notes that the hitherto separate field of information behavior theory is becoming integrated and mainstreamed into various other information science and technology topics, including system and web design and development.

Information behavior studies have recently penetrated virtually all other areas of information studies, and have thus become mainstreamed throughout many or most information science and technology topics. Judging by the content of *Annual Review* chapters published in the recent decade, it can be seen that the topic of information behavior is embedded into multiple chapter topics: social informatics, personal information management, communities of practice, web searching, HCI, workplace studies, information failures, information economics, gate keeping, multi-tasking, visualization, activity theory, museum informatics, and other areas.

In short, the domain of information behavior appears to be having greater impact, penetration, and applicability throughout other areas of information studies. Information behavior has developed into a core area of study in its own right, with increasingly greater conceptual rigor and its own eclectic methodology. Perhaps the time has arrived to further develop the area of information behavior into a super-ordinate or meta-level area of information studies, one that can be more iteratively and judiciously applied to the entire information life cycle and to the more rigorous development of information infrastructures.

Nevertheless, the outcome metrics currently used to assess the effectiveness of information seeking and retrieval appear to be inadequate as long-term, end-user outcome metrics. For example, such concepts as "user satisfaction," "relevance," and "usability" appear to serve as intermediate metrics, and do not necessarily serve to denote the successful culmination of inquiry, which is marked by the acquisition of major new insights or the solution to significant problems. As stated earlier, the use of personal, professional, or scholarly discovery might potentially serve as an outcome metric to mark the successful outcome of inquiry and to consolidate information behavior theories. Moreover, accelerated discovery methods can potentially be developed and applied to hasten breakthroughs throughout different domains of inquiry within the hard and soft sciences, professions, humanities, or in everyday life information seeking.

The following three sections present three scientific discovery models along

with a discussion of possible ways to accelerate discovery within the framework of each model. Examples of ways to create accelerated discovery information infrastructure platforms are then presented. The paper concludes by presenting evidence that justifies the need for a more unified vision for information studies education and makes a case for using accelerated discovery heuristics.

Chronological Discovery Model

A *first* model of the discovery process is based on historical case analyses, in which the key landmarks (sub-discoveries) that led to a given discovery are distributed along a timeline in order of their occurrence (Harmon, 1973). The first timeline landmark involves a foundational or seminal inquiry that stimulates subsequent investigation and leads to a related, second key landmark contribution (a sub-discovery). In turn, the first two landmark contributions stimulate further investigation, and lead to the third, fourth, fifth, sixth, and seventh landmark contributions or sub-discoveries. Finally, a culminating, major discovery synthesis of prior landmark sub-discoveries can be seen to occur. Each sub-discovery or landmark contribution tends to consolidate, abstract, and order minor findings into an integrated, holistic piece of knowledge—the major discovery itself (by way of analogy, pennies may be figuratively aggregated into nickels, nickels into dimes, and so on until a silver dollar is produced). That is, the culminating discovery represents an aggregation and ordering of sub-discoveries to produce an important contribution to knowledge.

Obviously, the interpretation of just which previous contributions or landmarks lead to a discovery is a matter of personal or collective interpretation. However, the person who makes the discovery synthesis tends to be well qualified to judge which prior contributions were essential to his or her synthesis. Those who make discoveries tend to cite, emphasize, and discuss specific prior works that were most instrumental in their construction of a discovery representation. Alternatively, the rigorous, corroborative accounts of three or more historians about the same discovery can lead to a reasonably objective interpretation of which key events lead to that specific discovery. Other historians might render quite different interpretations of given discoveries, but conflicting (secondary or tertiary) historical accounts can add insight to the dynamics of discovery. Ultimately, there is little choice but to rely on historical interpretations, both those provided by the discoverer or retrospectively constructed by other historians.

This author has analyzed the chronological timelines of numerous scientific discoveries, including these: Euclidian Geometry, Newton's derivation of fluxions (calculus), Newton's development of a theory of universal gravitation, unified geometry, thermionic emission, and Pauli's exclusion principle in physics (Harmon, 1973). Two examples of discovery are discussed below to illustrate briefly the nature of scientific discovery.

As a first chronological discovery example, the discovery of Euclidean Geometry involved a 300-year period ranging from the first contribution of Thales in 600 BC to Euclid's formulation of his plane geometry in 300 BC. The landmarks that led to Euclidean Geometry involved the following BC landmark contributions, according to a consensus of mathematics historians (Ball, 1927; Bell, 1945; Sarton, 1936; Smith, 1925; Struik, 1967); and Euclid's own account published in his *Elements of Geometry* (Fitzpatrick, 2008):

600 BC Thales: Thales Theorem (seminal work on angles and diameters in circles);

540 BC Pythagoras: Pythagorean Theorem of right triangles;

465 BC Oenopeides: Compasses, straight lines and perpendiculars;

460 BC Hippocrates: Quadratures of circles and π;

400 BC Archytas: Sphere analytics;
380 BC Plato: Definitions, postulates and
        axioms;
375 BC Theaetetus: Irrational numbers;
370 BC Eudoxus: Proportionalities;
300 BC **Euclidian Geometry Synthesis
        (major discovery).**

Euclid published his discovery synthesis in his classic work, *Elements*. If one plots these contributions on a percentage timeline, it may be seen that the seminal contribution of Thales occurs at 0% marker on the timeline; Pythagoras published his contribution at about 20%; Oenopeides at 45%; Hippocrates at 47%; Archytas at 67%; Plato at 73%; Theaetetus at 75%; Eudoxus at 77%; and Euclid (the major discovery synthesis) at 100% on the timeline. Euclidean Geometry effectively synthesized and ordered the prior contributions into a discovery of major significance, despite the fact that communications were slow and recorded knowledge was not plentiful or readily accessible.

Jumping ahead to more recent times, for illustrative purposes, a second example of a chronological discovery model can be seen within Wolfgang Pauli's own account (Pauli, 1964) of his discovery of the quantum exclusion principle in 1925. Pauli's breakthrough depended essentially on 35 years of synthesis of prior findings:

1890 AD J. Rydberg: Rydberg matter,
         atoms and orbits;
1896 AD P. Zeeman: Splitting of electron
         spin configurations in magnetic
         fields;
1913 AD N. Bohr: Atomic nuclei and
         electron orbits;
1916 AD A. Sommerfield: Atomic struc-
         tures and quantum mechanics
         equations;
1921 AD A. Lande: Magnetic field
         strengths and term analysis;
1924 AD E. C. Stoner: Principal quantum
         numbers;
1925 AD **W. Pauli's Exclusion
         Principle (major discovery).**

Rydberg's contribution occurred at 0% on the timeline, Zeeman's at 17%, Bohr's at 66%, Sommerfield's at 74%, Lande's at 88%, Stoner's at 97%, and Pauli's grand synthesis occurred at 100%.

By averaging the timeline percentages of the above two discovery cases with those of the four previously-mentioned mathematical and scientific discoveries made throughout the centuries, a crude, but generalized picture of the chronological discovery process (applicable to different eras and scientific disciplines) takes shape:

	Average	Timeline Position: Chronological
Event	Percent	Discovery Model
1	0 %	Initial, seminal contribution
2	24	Second key contribution
3	50	Third key contribution
4	60	Fourth key contribution
5	71	Fifth key contribution
6	83	Sixth key contribution
7	87	Seventh key contribution
8	94	Eighth key contribution
9	100%	**Major discovery synthesis**

The major discovery event occurs at the end of the timeline—at 100%. By recognizing a seminal inquiry (Event 1) and the next key contribution along the same line (event 2 at 24 %), one might anticipate that a discovery might possibly occur roughly four times the time span between events 1 and 2. Likewise, the culminating discovery can be predicted to occur at about twice the time span between events 1 and 3 (since event 3 tends to occur roughly one-half way between the first or seminal inquiry and the culminating discovery). Thus, given two or more sub-discovery events along the same line of inquiry, one can estimate when a major discovery will most likely occur, within a reasonably narrow confidence interval.

A sufficient number of discovery estimates, based on access to major prior contributions, can be seen to form a statistical distribution of estimators grouped

around the probable discovery event, with its own statistical characteristics of central tendency and variability. While such estimates are admittedly crude, they could be refined by looking at a larger number of cases within the same disciplinary or sub-disciplinary area. Thereby, we can obtain a clearer picture of the discovery process, as well as sets of predictors to anticipate future discoveries, in each area of scientific or mathematical inquiry.

Obviously, an analysis of the nature of discovery patterns in each of the social sciences, or in such professions as medicine or engineering, requires intense analysis to detect each area's commonalities and differences. Likewise, humanistic inquiry can be studied for the ways in which novel and creative themes are developed. Humanistic inquiry has yielded rich insights throughout the ages, and these insights could be explored and reinterpreted for their implications during different time periods. For example, different forms and specific works of poetry, sculpture, painting, and music suggest different sets of subjective meaning for different audiences throughout different time periods. Nevertheless, scholars such as C. P. Snow have argued that the intellectual life of Western civilization has been split between the sciences and the humanities, and that this split has hindered solving many of the world's problems (Snow, 1963). Wilson (1998) also argued that civilization would be better served through consilience—the creation of a unified body of knowledge that incorporates all areas of knowledge.

Another observation about the nature of discovery is that the sub-discoveries or landmark contributions that lead to most scientific discoveries tend to be limited to an average of seven or so contributions along each timeline. This numerical limitation appears to stem from the limits of human short-term working memory. Humans can process an average of about seven plus or minus two cognitive chunks in their respective working memories, according to Miller's classical article (Miller, A. M.,

1956). If more than seven or so chunks are available to be synthesized into a discovery, their numbers tend to overwhelm the limits of short-term memory, despite the fact that the inquirer can use various kinds of external props and knowledge representations to deal with large volumes of data. Gaining cognitive manageability still challenges the limits of short-term human memory. Accordingly, prior contributions along the same line of inquiry need to be synthesized periodically or inquiry can become log jammed with past findings and scientific progress can grind to a halt.

How then can scientific discovery be *accelerated* in terms of the above chronological model? Recall that Pauli's discovery discussed above required a time span of 35 years for its making nearly a century ago. Currently, it appears to require about one to three decades of prior investigation to synthesize a significant scientific breakthrough. Through various time compression approaches, new discoveries might be possible to achieve within much shorter time spans—within one to five years, for example.

While one might argue that it will *always* require fairly long time spans to make new discoveries, we are now blessed with relatively new technologies to publish, communicate, share ideas, and engage in debate. These relatively new technologies include the personal computer, the internet and web, e-mail, electronic books and journals, wikis, data analytic resources, automatic translators, mobile communications, social networking, and the like. We can now synthesize data and previous insights rapidly and publish findings more quickly. Obviously, these technologies did not exist in ancient Greece, during the middle ages, or during the early 1900s. Accordingly, the argument that it will always require long time spans to synthesize new discoveries appears to be less well supported nowadays.

Discovery acceleration might require one or more of the following approaches. First, prior contributions should be made

readily available to enable rapid synthesis of findings. The availability of prior findings would require retrospective searching capability ranging back about a century in the sciences to be on the safe side, even though Nobel laureate discovery syntheses appear to occur in one to three decades at present (Balcom, 2005).

All this points first to the necessity of preserving recorded knowledge and artifacts in hard copy form (as well as in their digital forms) over extended periods of time to support discovery in the sciences, humanities, social sciences, professions, and newly emerging areas of knowledge. Digitization efforts sometimes fail to extend back historically very far at present; hence digitization is not yet a panacea. Hard copy information publications and artifacts still play an instrumental role in the discovery process. Second, information retrieval heuristics should therefore assure the capability of recognizing seminal inquiries and their successor inquiries that might potentially foreshadow a discovery (Harmon, 1978). Third, there should be informational support to help researchers organize prior key findings, especially after a critical mass of about seven key contributions has occurred along the specific timeline relevant to the potential discovery. Thereby can be a faster synthesis of prior key findings.

But having easy access to prior findings might not necessarily contribute to making discoveries more rapidly, since many prior findings might be irrelevant or even misleading. Nevertheless, the persons who make discoveries tend to possess expertise and are well steeped in their respective fields. They thus tend to be capable of generating and checking out different hypotheses rapidly, and can usually dismiss irrelevant, marginally relevant, or misleading information appropriately.

Information Acquisition and Ordering Discovery Model

A *second* model of the discovery process is somewhat akin to a cognitive jigsaw puzzle, in which pieces of the puzzle are acquired and ordered until a composite picture of some knowledge domain is formed. The mathematics of set theory may be used to provide a simplified representation of a researcher's gradual and iterative acquisition and ordering of information chunks or elements and to eventually shape a discovery. Goffman and Harmon (1971) used Harmon's set theory model to explain the cognitive dynamics of the discovery process and predict discoveries in symbolic logic. A discovery outcome may be said to consist of a complete, ordered set of cognitive elements: $D = \{a, b, c, d, e, f, g\}$. That is, the discoverer arranges a complete group of cognitive chunks into an ordered, meaningful set to represent the discovery in terms that reflect human short-term memory limitations (about seven plus or minus two chunks). This final discovery outcome may be characterized as the culminating final stage (Stage IV) of the discovery process, wherein there exist a sufficient number of chunks and these chunks are properly organized. But the discover must progress repeatedly through other stages (Stages I, II, and III) to arrive at the Stage IV discovery state as described below.

Stage I, which represents the outset of inquiry, consists of an empty or null set: { }. An empty set of cognitive elements is used because there is *insufficient* information and therefore *none to order*. For example, a scientist might attack a problem about which little is known and the problem itself is hardly even defined. Thus, few concepts or chunks exist at the outset of inquiry, but few or no chunks have been gathered, so organization problems are unlikely to occur.

Stage II, *insufficient* but *ordered* information, occurs when the scientist tentatively designates several information elements or chunks as relevant to the inquiry. The number of elements is sufficient to establish set ordering relations and to imply the bounds of a cognitive set: $\{a, \ldots$

d, e, g}. After ordering the available information the task is to discern what else needs to be known to fill in the gaps, and this calls for additional retrospective and concurrent searching.

Stage III, *sufficient* but *unordered* information, occurs when the scientist or inquirer has acquired a sufficient number or even a surplus of information elements: {a, x, f, c, d, e, b, g, k}. At this stage, the researcher might appear to be cognitively overloaded, since the limits of human short-term working memory have been exceeded, and ordering problems further confound inquiry. The inquirer must kick out the irrelevant chunks x and k, and order the remaining relevant chunks to achieve a cognitively manageable array of about seven chunks.

Finally, at Stage IV, the researcher arrives at a culminating *sufficient* and *ordered* information set, and this stage completes the main research task and constitutes a discovery: $D = \{a, b, c, d, e, f, g\}$.

During the above process of acquiring and ordering information elements that lead to a discovery synthesis, it might sometimes be seen that novel elements or new novel configurations are obtained. Harter (1986) and other information retrieval scholars have discussed novelty as one basis for retrieving citations not previously known to the researcher or not initially judged to be relevant.

The discovery process might thus be regarded as a dynamic, iterative, and trial-and-error process in which cognitive chunks are obtained and permuted until a complete, ordered discovery set is obtained and verified. Obviously, there would not be a simple progression through Stages I, II, and III to get to Stage IV, but rather a convoluted progression, where one can go from any Stage to any other several times. But once a discovery is completed, the discovery state of Stage IV appears to be only temporarily stable, since new discoveries tend to generate new questions and often serve to inspire antithetical dialog. Thomas Kuhn, for example, originally argued that the growth of scientific knowledge is not necessarily gradual or cumulative but proceeds on the basis of revolutions against old paradigms. As a result, new world views of scientific phenomena occur after a paradigm shift and these new world views tend to require different approaches to gathering and measuring information. However, in response to criticism Kuhn later modified his original model of scientific revolutions to accommodate the earlier gradualist and cumulative models of normal science (Kuhn, 1996).

How might the above information acquisition and ordering model be used to accelerate the discovery process? There needs to be recognition of the need to *time* the provision of searching and other supportive services and deployment of systems and to gear them to the different stages of inquiry. In Stage I (insufficient information), contextual, background, and state-of-art information is needed to identify key concepts and data essential to clarifying the nature of the research problem at hand. In Stage II (insufficient but ordered information), there is a need to acquire and sift through primary and secondary sources to find data to elaborate the research problem, generate the right questions, and check out preliminary hypotheses. In Stage III (sufficient but unordered information), there is a need to abstract and order the acquired data and concepts, and to discard or set aside data or ideas that no longer appear to be very relevant to the transformed problem. Different or refined theories and concepts are thus needed to make sense of findings. Finally, in the discovery state, Stage IV (sufficient and ordered information), results need to be checked to assure their validity or trustworthiness, and general applicability, and to pose new questions and directions for future research.

A systems ontology model, discussed next, appears to be particularly suitable for the task of guiding the acquisition and ordering of information.

Systems Ontology Discovery Model

A *third* discovery model involves the strategic deployment of general systems theory concepts to guide and prompt discovery. As a result of a joint multi-year analysis of 62 autobiographical Noble laureate discovery accounts in physiology or medicine (published between 1901–1990) conducted by the author and his doctoral student, it was realized that these Nobel discoveries could be regarded as new or reworked conceptual systems. These conceptual systems explained normal and pathological structures and processes which tended generally to occur at the cellular, organ or organism biological levels (Balcom, 2005). Accordingly, each discovery account could be mapped nicely onto J. G. Miller's systems ontology model (Miller, J. G., 1995, xiii–xxv).

Briefly, Miller's systems ontology model uses two matrices, one of which explains the body system's matter and energy processing (food, water, air) subsystems at the cellular, organ or organism levels. A second matrix explains the body system's information processing (sensory and motor) subsystems, likewise at the cellular, organ or organism levels. Each Nobel laureate's explanation of his or her own discovery at the matter-energy level can be decomposed and mapped onto the ingestor, distributor, converter, producer, storage, extruder supporter or motor subsystems of cells, organs or organisms. Likewise, each laureate's discovery description of information processes could be mapped onto input, internal and output transducer subsystems, as well as decoder, transducer, channel and net, timer, associator, memory, decider, and encoder subsystems, at the cellular, organ or organism levels. The systems ontology model is similar in many respects to the information acquisition discovery model discussed above, but the systems model furnishes more specificity throughout the task of acquiring and ordering information elements to complete an ordered discovery configuration.

Additionally, it was surprising during this Nobel laureate discovery pattern research to find (after completing a count of substantive sections of each laureate's discovery account) that each Nobel laureate tended to use seven or so substantive subsections in their autobiographical accounts to describe their discovery. An analysis of 62 Nobel laureate discoveries that included separate substantive sections, and which occurred between 1900 and 1990, revealed that the 62 discovery accounts possessed a range of two to 16 substantive subsections, but with a mean number of 7.1 sections and median of 7.0 sections, with a standard deviation of 2.84 and standard error of the mean of 0.36 (Balcom, 2005, p. 77–82). This finding confirmed A. M. Miller's classical notion that concepts tend to consist of seven plus-or-minus-two cognitive chunks (Miller, A. M., 1956), which seems to be particularly true when dealing with recorded knowledge.

How can discovery be accelerated through use of the systems ontology model? Information professionals might well learn systems theory (which now embodies chaos theory) to describe or explain phenomena treated within all areas of personal, professional, or scholarly knowledge and throughout the arts, humanities, sciences, and social sciences. For example, within physiology or medicine, systems ontology discovery templates embedded in human-computer interfaces could be used to prompt researchers toward the revision and completion of previously developed concepts, or the development of new ones, at the cellular, organ and organism levels. In a similar fashion, systems theory has been applied in the social sciences, humanities, and in cosmological research, as well as throughout professional domains.

Creating Accelerated Discovery Information Infrastructure Platforms

As discussed above, information be-

havior theory, with the inclusion of accelerated discovery heuristics, might be applied to guide more closely and strategically the development of information resources and rendering of services. This section discusses some very general potential features of what this author refers to as accelerated discovery infrastructures.

First, in terms of the Chronological Discovery Model discussed above, searching along timelines to identify and retrieve the seminal and subsequent contributions that might potentially fuse into a discovery is vital to discovery acceleration. Discovery times might be compressed through the development of retrieval systems based on patterns of discovery (Harmon, 1978). Recent scientific discoveries tend to be the result of synthesizing about six to nine key contributions that go back at least 10–30 years, but supportive infrastructures would require longer retrospective searching and retrieval capability. Additionally, an infrastructure and its services should have the capability of helping to organize and reorganize prior contributions into meaningful wholes, which might turn out to be a discovery. Information professionals could be effective players in the discovery process by becoming versed in the discovery histories of their respective fields. The new area of literature-related discovery (LRD) centers on detecting significant and strong relationships between two or more heretofore unrelated (disjoint or balkanized) bibliometric clusters. Such relationships enable collaborators or individuals to discern critical relationships essential to accelerating scientific discovery (Kostoff *et al.*, 2009). The emergent field of knowledge discovery and its variations (data, information or web mining; knowledge discovery in databases or KDD; pattern discovery; information extraction; text mining; data analytics) deploys algorithms to thread through large arrays of raw data to form information aggregates. The end result is often the detection of novel or otherwise overlooked critical themes and relationships that yield new insights, mod-

els or even key discoveries. While citation data are not excluded in knowledge mining, the main emphasis centers on mining non-citation databases (Benoit, 2002).

Second, the Information Acquisition and Ordering Discovery Model discussed above points indirectly to the need to *time* the provision of search and other supportive systems to support the different stages of inquiry, alternating between the identification and retrieval of key knowledge elements and their ordering and reordering until a discovery configuration and breakthrough occurs, and to help verify results. In other words, various theoretical frameworks (or even different paradigms) are needed to make sense of findings.

Third, the Systems Ontology Discovery Model discussed above implies that information professionals could become well versed in General Systems Theory to understand better the phenomena treated within all areas of knowledge. Because discoveries are themselves conceptual systems, systems ontology discovery templates could be the basis for designing human-computer interfaces to prompt researchers toward discoveries. For example, the Periodic Table of Chemical Elements provides an actual example of a discovery template that continues to accommodate the discovery of new chemical elements.

Discovery acceleration platforms might be developed through additional approaches.

Shneiderman (2007) provides an insightful summary of progress in the development of creativity support tools to promote accelerated discovery and innovation. These tools and approaches include new generation search engines; hypothesis generators; collaborative education; research and engineering; improved Wikimedia; artist-technologist collaborations; and other active interfacing methods. Harmon and Ballesteros (1997) report on their experiments that demonstrated the feasibility of subjecting researchers to an audiovisual stimulation interface device to

induce deep relaxation (theta brainwave state of 4–14 Hertz), which significantly helped the researchers to frame effective research questions. Biofeedback has been successfully used produce the "Aha!" experience in experimental participants (Wilson, Pepper, & Gibney, 2004).

Conclusion: A Strategic Educational Vision

In summary, this paper explores and argues for the development of a new strategic objective for LIS and iSchools—that of promoting and accelerating personal, professional, and scholarly discovery throughout society. Pursuit of this objective would be done through research on ways to accelerate discovery in all areas of inquiry, through educating students and alumni, and through operational practitioner alliances. Thus, in addition to such metrics as relevance, usability, and user satisfaction, discoveries can be used as operational outcome metrics for information professionals and their clientele. Three models of the scientific discovery process are discussed to provide a basis for exploring ways to accelerate discovery.

While this paper has focused on a broad, scientifically-oriented model of discovery phenomena, one can argue that there are other outcomes involved in the culmination of inquiry, such as an aesthetically pleasing outcome that serves the purposes of one or more inquirers. Such outcomes can vary considerably from the outcomes of validity and reliability demanded in the strongly empirical sciences. In the humanities, for example, a poet or painter might produce aesthetically pleasing outcomes that are notable over extended periods of time. Or some areas, such as psychiatry, might require a blending of biochemistry with poetry or music. An individual might "discover" his or her calling. A young person might "discover" that they possess musical or mathematical talent. Thus, "truth" becomes something contingent, more related to different circumstances, emotions, environments, times, places, individuals, cultures, and so on.

A potential role for educators could be to develop the art and science of inquiry by placing a high priority on the development of information behavior theory with an emphasis on search, research, and discovery. Such a body of theory could be deployed as a basis for developing and redeveloping what this author terms discovery acceleration infrastructures—new information architectures that would incorporate literature-related discovery; long-term retrospective retrieval; knowledge and data mining; overall digital asset management; biofeedback interfaces to enhance creativity, and the like.

At present, education for information professionalism can be characterized as not having a very clear focus or integrative purpose. Deans at the First iConference of the iSchool Communities tended cautiously to regard the still emergent iSchools as relatively new, experimental educational platforms to accommodate multi-disciplinary education and research appropriate for the rapid changes in all information environments; they deferred the articulation of a unified objective (Harmon, 2006b). Mezick and Koenig (2008) review the status of information studies education and conclude that the education currently lacks consensus about its core focus and struggles to achieve identity and achieve reasonable consensus about future directions. In so doing, Mezick and Koenig echoed this author's 1976 review of information science education and its conclusion that educational curricula could benefit by having a more abstract, unified, and user-oriented focus to address the broad range of information problems being addressed (Harmon, 1976). Similar confusion has existed throughout European LIS education, with its "variety of epistemological frameworks, the patchwork of national traditions, cultures and languages and the multiplicity of LIS educational practices. . . ." (Kajberg, 2007, p. 69). Likewise, Asian nations have

struggled to redefine the identity of LIS by addressing the needs for new job markets for graduates, to accommodate employers' requirements, to connect research and practice, and to enhance the social standing of the field (Miwa, 2006). In the US, recent controversies about ALA accreditation requirements of LIS and iSchools have seemingly tended to accentuate factional differences, rather than common themes and an integrative vision.

This paper argues for a clearer collective direction for future information education, research and practice, which might be achieved by placing a priority on the acceleration of personal, professional and scholarly discovery—particularly through adopting the priority of developing a superordinate level of information behavior theory. Such theory could be applied appropriately throughout information architecture development cycles to build infrastructures based on search, research, and discovery acceleration. In her outstanding book contribution, Neway (1985) proposes a greatly expanded role for information specialists as proactive members of research teams. Such research-oriented information specialists could even fulfill research leadership roles in many types of organizations and other marketplace settings throughout society. Dillon (2008) takes Neway's concepts further by proposing that a key objective for information education and professionalism in the context of rapidly emerging digital environments is to produce graduates who can facilitate accelerated end-user learning and discovery. The embedded *Informationist* specialty has emerged in recent years, largely in clinical health and medical research settings, to provide evidence-based information for doctors, nurses, and other health professionals (Rankin, Grefsceim, & Canto, 2008). In her ASIS&T Award of Merit Speech, Tenopir (2009) stressed the need for information professionals to enhance scientific discovery through appropriate professional and multidisciplinary communications and the preservation of research for future generations.

In making the above arguments, it should be understood that discovery modeling and acceleration are not the *only* thrusts that might serve to spearhead LIS and iSchool education. Obviously, competing thrusts might well be selected by particular schools. Other schools might appropriately select a different thrust or a plurality of missions and orientations, depending on such factors as their respective location, circumstances and the qualifications required of their graduates.

An audacious strategic vision for LIS and iSchools could also involve efforts to partially embed themselves into research funding agencies and into their respective university's research administration leadership divisions. LIS and iSchools could thereby lead in accelerating discovery via the development of meta-theories of search, research and accelerated discovery, thus making their mission more compatible with that of their parent universities and research funding agencies. This effort would involve the consolidation of key search engine heuristics and algorithms and of quantitative and qualitative research methodologies from a multitude of disciplinary and professional domains. Deployments of highly effective multidisciplinary search and research methods could thus bring about the diffusion of accelerated discovery processes throughout various areas of personal, professional, and scholarly inquiry (Harmon, 2006a).

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