Agent-based Modeling of Nursing Opinion Leadership: A Philosophic Analysis and Exemplar Case of a New Theory Development Tool for Nursing

by

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To my mom, Ingrid Anderson, RN, whose inspiration and support remain constant.

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List of Abbreviations

ABM	Agent-based model
ABMS	Agent-based model and simulation
OL	Opinion leader, leadership
TD	Theory derivation
OCL	Organization of Cognitive Labor
B & OCL	Bayesianism and Organization of Cognitive Labor
NOL	Nursing opinion leader, leadership
NOLM	Nursing opinion leadership model
NOL-ABMS	Nursing opinion leadership agent-based model and simulation

Abstract

The purpose of this dissertation was to: examine agent-based modeling (ABM), a new methodological tool, from a nursing philosophy standpoint; evaluate its disciplinary fit; and use the tool for creating and testing a model of nursing opinion leadership.

First, in a philosophic analysis of ABM, recurrent themes concerning the use of ABM in multidisciplinary research were identified. These themes (heterogeneity, dynamics, adaptation, emergence, and the metaphorical use of the term “bridge” to describe ABM) were examined from various philosophical positions in nursing. The ABM themes were found to be compatible with multiple philosophic viewpoints within nursing. Further analysis, linking the recurrent themes with nursing metanarratives via exemplars from nursing systems research, revealed that ABM is a methodological tool that is congruent with nursing values.

Next, a model of nursing opinion leadership, derived from two philosophic theories of belief formation was developed. The resulting model was then programmed as an ABM. Simulated data, obtained from model execution, depicted opinion leadership as a dynamic process that develops under conditions of uncertainty when credible individuals are available to act as opinion resources. Overall, this dissertation demonstrated the usefulness of ABM as a methodological tool for theory development in nursing.

Chapter I

Introduction

Today's focus on evidenced-based practice in the provision of nursing care requires that nurses are current on information and able to enhance the application of information in practical usage. According to the Institute of Medicine (IOM) in *Crossing the Quality Chasm* (2001) the average time it takes for the results of randomized controlled trials to reach practice application is an astonishing seventeen years. Enhanced dissemination is needed. Opinion leaders, defined as informal leaders who have the ability to influence others' decisions about adopting new products, practices or ideas, have been identified as an important factor in the adoption of new innovations (Rogers, 2003). Understanding the role of opinion leaders and their means of influence can help effectively promote timely evidence-based nursing practice. Despite their perceived importance, results from opinion leadership research in health care remain mixed. Reviews of opinion leader research in health care point to the complexity of the phenomenon and the resulting methodological issues Factors include a lack of clear definition of opinion leadership and its contextual nature. Also cited was the non-linear nature of communication and that opinion leadership is one part of a complex process. (Doumit, Gattellari, Grimshaw, & O'Brien, 2007; Greenhalgh, Robert, Bate, McFarlane, & Kyriakidou, 2005; Locock, Dopson, Chambers, & Gabbay, 2001). Greenhalgh and

colleagues noted a mismatch in results between qualitative and quantitative studies and advocate a mixed method approach (Greenhalgh, Robert, Bate et al., 2005).

The *Crossing the Quality Chasm* (2001) report also challenged the health care industry to develop a complex systems approach to understanding and solving system problems such as the failure to adopt new practices based on current research findings. The increasing use of a complex systems view to study problems in health services research has lead to discussion concerning methodological issues such as those encountered by opinion leader researchers. According to Berwick (2005) the randomized clinical trial, though important and useful in some situations is not suited to the study of problems with vague hypothesis or those in which context is a key factor. Lamb (2007) also emphasized the need to match methods with research questions but lamented the gaps in theory development in nursing systems research. Research in nursing systems requires increasingly sophisticated research methodologies to address non-linear, multi-level and dynamic phenomena (Lamb, 2007; Mick & Mark, 2005).

Agent-based modeling is a methodological tool that is increasingly being used to aid theory development concerning complex systems. Agent based modeling (ABM) is the process of representing a collection of individual “agents” and the system of relationships among them. Agents individually possess attributes, are autonomous, and are able to make decisions based on a set of rules and exhibit behaviors as a result (Bonabeau, 2002). The use of ABM has increased in part because of its usefulness for enhancing understanding of complex systems. Among the advantages of ABM over traditional methods are; flexibility in representing behaviors, a process orientation, agent adaptability, dynamics and timing considerations, agent heterogeneity, scalability,

repeatability and the ability to generate emerging phenomena. From a practical standpoint, ABM is cost-effective. The process of creating and refining an ABM is a potential source of insights that go beyond the theory or problem being modeled (Miller & Page, 2007)

Twenty-five years ago Rosemary Ellis, an influential nursing scholar devoted to knowledge development (Algase & Whall, 1993; Pressler & Fitzpatrick, 1988), called for an increase in philosophic inquiry by nurses (Ellis, 1983). Ellis (1983) has stated that philosophic inquiry is much needed to identify and clarify important disciplinary issues, including methodology. The purpose of this dissertation was to: examine agent-based modeling, a new methodological tool, from a nursing philosophy standpoint; evaluate its disciplinary fit; and use the tool for creating and testing a model of nursing opinion leadership. The specific aims below, are followed by a brief overview of the dissertation chapters.

The overall aims of the dissertation are to:

1. Extend philosophic inquiry methods in nursing by:
    a. Exploring abstract philosophical issues related to methodology and theory development from the perspective of neomodernism and complex systems theory.
    b. Propose the use of agent based modeling as a methodological tool that is congruent with disciplinary values and truth criteria.
2. Develop a new understanding of opinion leadership by:
    a. Formulating a partial theory of opinion leadership based on explicit philosophical assumptions.

b. Constructing a provisional agent based model and simulation of opinion leadership.

c. Evaluating the partial theory of opinion leadership using model verification and validation procedures

The dissertation follows the three-paper model and includes the introduction and a concluding chapter. The first paper is a philosophical analysis of agent-based modeling that focuses on methods for theory development in nursing. The agent-based model is proposed as a methodological tool that is useful for advancing nursing science. The analysis focuses upon congruence of agent-based modeling with changing philosophic views of science within nursing as well as disciplinary values and truth criteria. The basic framework for this philosophic analysis will draw on the work of Whall, Sinclair and Parahoo (2006) and Reed (1995, 1997, 2006a, 2006b)

The second paper moves the focus to the second overall aim, developing a new understanding of opinion leadership, by describing the construction of a model of the phenomenon. Model development begins with explication of the philosophic foundations as a framework. Using Walker and Avant's (2005) theory derivation procedure as a guide, the focus was Bayesian epistemology as described by Joyce (2004, 2005) and the social epistemology described by Kitcher (1993). These two theories of rational belief were analyzed for major concepts and relational statements and selected elements were synthesized to form a multi-level (individual and community) model of opinion leadership.

The third paper describes the construction of an agent-based model by programming into the computer, selected attributes and processes from the model developed in paper two. Following construction of the model, the paper focuses on initial verification and validation of the agent model. Verification refers to testing the model in terms of logical coherence and proper representation of the concepts in the coding procedure. Validation refers to an important step that contributes to the credibility of the model. Validation procedures included two types of simulation which were designed, executed and statistically analyzed to test model predictions (Gilbert, 2008; North & Macal, 2007).

The final chapter of this dissertation offers a summary of the three papers, a discussion of the results in light of the specific aims and describes avenues for future research based upon this dissertation.

References

Algase, D. L., & Whall, A. F. (1993). Rosemary Ellis' views on the substantive structure of nursing. *Image - Journal of Nursing Scholarship, 25*(1), 69-72.

Berwick, D. M. (2005). The John Eisenberg lecture: health services research as a citizen in improvement. *Health Services Research, 40*(2), 317-336.

Bonabeau, E. (2002). Agent-based modeling: methods and techniques for simulating human systems. *Proceedings of the National Academy of Sciences of the United States of America, 99 Suppl 3*, 7280-7287.

Doumit, G., Gattellari, M., Grimshaw, J., & O'Brien, M. A. (2007). Local opinion leaders. Cochrane effective practice and organisation of care group. *Cochrane Database of Systematic Reviews, 1*.

Ellis, R. (1983). Philosophic inquiry. *Annual Review of Nursing Research, 1*, 211-228.

Gilbert, N. (2008). *Agent-Based Models*. Thousand Oaks, CA: Sage Publications.

Greenhalgh, T., Robert, G., Bate, P., McFarlane, F., & Kyriakidou, O. (2005). *Diffusion of Innovations In Health Service Organisations: A Systematic Literature Review*. Oxford: Blackwell Publishing Ltd.

Institute of Medicine Committee on Quality of Health Care in America. (2001). *Crossing the quality chasm: A new health system for the 21st century*. Washington, DC: National Academies Press.

Lamb, G. S. (2007). Advancing nursing systems research. *Research in Nursing and Health, 30*(4), 358-360.

Locock, L., Dopson, S., Chambers, D., & Gabbay, J. (2001). Understanding the role of opinion leaders in improving clinical effectiveness. *Social Science and Medicine, 53*, 745-757.

Mick, S. S., & Mark, B. A. (2005). The contribution of organization theory to nursing health services research. *Nursing Outlook, 53*(6), 317-323.

Miller, J. H., & Page, S. E. (2007). *Complex Adaptive Systems: An introduction to computational models of social life*. Princeton: Princeton University Press.

North, M. J., & Macal, C. M. (2007). *Managing business complexity: Discovering strategic solutions with agent based modeling and simulation*. New York: Oxford University Press.

Pressler, J. L., & Fitzpatrick, J. J. (1988). Contributions of Rosemary Ellis to Knowledge Development for Nursing. *Journal of Nursing Scholarship, 20*(1), 28-30.

Reed, P. G. (1995). A treatise on nursing knowledge development for the 21st century: beyond postmodernism. *ANS Advances in Nursing Science, 17*(3), 70-84.

Reed, P. G. (1997). Nursing: the ontology of the discipline. *Nursing Science Quarterly, 10*(2), 76-79.

Reed, P. G. (2006a). Commentary on neomodernism and evidence-based nursing: implications for the production of nursing knowledge. *Nursing Outlook, 54*(1), 36-38.

Reed, P. G. (2006b). The practice turn in nursing epistemology. *Nursing Science Quarterly, 19*(1), 36-38.

Rogers, E. M. (2003). *Diffusion of Innovations* (Fifth ed.). New York: Free Press.

Whall, A. L., Sinclair, M., & Parahoo, K. (2006). A philosophic analysis of Evidence-Based Nursing: recurrent themes, metanarratives, and exemplar cases. *Nursing Outlook, 54*(1), 30-35.

Chapter II

A Philosophic Analysis of Agent-Based Modeling: A New Tool for Theory Development in Nursing

Chapter Abstract

Agent-based modeling and simulation (ABMS) is a new methodological tool used to study complex systems. Because of the growing interest in complexity science within the discipline of nursing, this new tool may prove useful for nurses engaged in research and theory development. The purpose of this philosophic analysis was to examine the nature of ABMS from nursing's' philosophic perspectives and truth criteria as a means of evaluating its disciplinary fit. Recurrent themes concerning the use of ABMS were identified and include heterogeneity, dynamics, adaption, emergence and "bridging". The recurrent themes were congruent with philosophic views and metanarratives in nursing, leading to the conclusion that the use of ABMS, as tool for nursing theory development, should be expanded.

Introduction

The application of new knowledge arising from the rapidly growing field of complexity science has important and exciting implications for the advancement of nursing knowledge (Chaffee & McNeill, 2007; Clancy, 2004; Holden, 2005). The development of new methodological tools used to study complex systems, specifically agent-based modeling and simulation, has fueled the growth of the study of complex systems in many disciplines (Bankes, 2002a; Grim, 2004; Holland, 1995, 1998; Miller & Page, 2007).

Within nursing, Ellis (1983) has stated that philosophic inquiry is much needed to identify and clarify important disciplinary issues, including methodological inquiry. The purpose of this philosophic analysis, therefore, is to examine the nature of agent-based modeling and to evaluate its fit within nursing via comparison with disciplinary values and existing truth criteria.

The philosophic analysis method used in this study is based upon that of Whall, Sinclair and Parahoo (2006). The steps include the identification of recurrent themes concerning the use of agent-based modeling as a methodological tool for theory development, and an examination of agent-based modeling from three philosophy of science viewpoints with nursing. Examples from nursing systems research are then used to demonstrate the link between the recurrent themes and nursing metanarratives in order to evaluate disciplinary fit.

Definition of agent-based modeling

It is important at the outset to identity a clear definition of agent-based modeling (ABM). Not only are there a number of different labels used (e.g. computational models, multi-agent systems) but also, the term model itself is subject to multiple meanings. For the purposes of this analysis, the term model is defined as an abstract representation of concepts and their related empirical referents (Grim, 2004; Henrickson & McKelvey, 2002). The term “agent-based model” or ABM refers to the computerized representation of dynamic, individual entities (agents), their behaviors and interactions (Bonabeau, 2002).

According to Macy and Willer (2002), the possibility of modeling individual agent interaction and adaptation at the local level are important differences between

ABM and other types of models and simulations. They describe four key assumptions related to ABM. First, agents are autonomous, meaning that interactions are based on individual agent decision-making. Although agents are autonomous, the second assumption about ABM is that agents are also interdependent. This means that the outcomes resulting from an individual agent's behavior affects the behavior of the other agents. If one agent does something to change the environment, for example, it may affect the choices other agents make in response. The third assumption is that agents individually follow simple rules. ABM are used to explore how these simple individual behaviors result in complex patterns at the population level of the agent environment. Finally, agents are adaptable. Examples of the ways in which agents adapt include learning and evolutionary behaviors such as selection (Macy & Willer, 2002)

Separating different details from the underlying key structure of a phenomenon in order to provide a useful representation is essential to the process of creating a good model (Miller & Page, 2007). According to Miller and Page (2007), the range of a model's detail, from simple to complicated, is central to the link between agent-based modeling and simulation. As the underlying structure of an ABM becomes more complicated (for example by iteratively adding details) the model can become a simulation. At what point there is a transition from a model to a simulation is not well defined in ABM discussions. The definition of the ABM addressed in this paper is that of a dynamic computerized representation of individual agents and their interactions (regardless of the level of detail symbolized).

Recurrent themes

The literature was searched for articles addressing ABM. The search strategy was adapted from Greenhalgh and colleagues method for systematically reviewing complex and multidisciplinary literature (Greenhalgh & Peacock, 2005; Greenhalgh, Robert, Bate et al., 2005; Greenhalgh, Robert, Macfarlane et al., 2005). Electronic indexes and iterative bibliographic searches were used; this process initially resulted in a large data set of >17,000 citations. Subsequently limiting the results to social science, resulted in a reduction in the number of citations to approximately 2500 papers and abstracts in 130 subject categories. Review and elimination of several subject categories, and the abstracts, resulted in additional reductions. Seminal papers (defined as early works and frequently cited papers) were identified, and traced by chronological ordering and via manual and electronic examination of bibliographic sources.

Following the storylines of the seminal works resulted in higher-level categorization of the diverse social science disciplines represented. Review of approximately 500 citations by title and abstract, resulted in 156 papers and books for full text review. The search yielded one nursing study, as well as a limited number from related fields such as medicine and public health. The final selection of studies included in the thematic analysis reflects this diversity.

Criteria for inclusion in this phase included an assessment of the completeness of the research report in terms of the purpose, explication of the methodological considerations for the use of ABM and the results. Despite the range of disciplines and topics, a number of recurrent themes, emerged from the content analysis. These themes (defined as prominent issues or topics described in the studies) include heterogeneity,

dynamics, adaptation, emergence and the metaphorical use of the term “bridge” to describe ABM. A description of each of these themes is further explicated below.

Heterogeneity

The first key theme identified is that of the heterogeneity of agent attributes, their behaviors and their environment and the ability of researchers to represent heterogeneity using ABM. The increase in computer power in recent years has allowed the development of software tools that can handle the previously insurmountable mathematical computation required to analyze multiple variables and the interactions among them (Gilbert & Bankes, 2002; Holland, 1998). The ability to model individual agent characteristics is a primary benefit for using ABM. In addition to demographics, such as age or income level, other agent attributes such as preferences or social attachments can be included in the model (Bankes, 2002a). Agent specification, the process of defining agent characteristics, is often iterative and may start out as highly idealized and general, yet still be sufficient to generate macroscopic phenomena of interest (Epstein, 2002).

The representation of heterogeneous behaviors is a benefit of ABM. Specifically, decision-making is central to agent behavior. The process used by an agent to make a decision is one dimension of decision-making; another is the number and kinds of options available to agents. The ability to vary assumptions about the rationality of agents to account for individual differences in decision-making contributed to the growth and development of the method in fields such as economics and political science (Bankes, 2002b).

In an example from anthropology, Kuznar (2007) compared multiple ABMs, each representing a different decision strategy used by agents to select a political leader. Statistical analysis of the results obtained from simulations using the various models revealed that more than one strategy resulted in outcomes comparable to the real world data as described in a detailed ethnography.

Heterogeneity of environmental factors is also clearly illustrated by ABMs in which the physical space is a key factor. Examples include models that range from basic representations of neighborhoods (Gorman, Mezic, Mezic, & Gruenewald, 2006) to sophisticated, highly detailed models that use, for example, actual population, land use and climate data from various sources (Eubank et al., 2004; Kuznar, 2006).

Other models focus on the virtual space of social network structures. For example, in a study about the development of shared identity in idea diffusion, the neighborhood was defined as the social connections and interactions among agents, not the geographical space (Rousseau & Van der Veen, 2005). Recent work by Christakis and Fowler explore the effects of social networks on the spread of obesity (Christakis & Fowler, 2007) and smoking cessation (Christakis & Fowler, 2008). The researchers developed their network models from longitudinal data collected as part of the Framington Heart Study. Among the key findings in both studies were the comparisons between the social network environment and the geographical space. The studies showed that there was a significant effect of social network proximity on behaviors. ON the other hand, geographic proximity of individuals was not found to significantly influence either stopping smoking or gaining weight. Heterogeneity of agent attributes, environments and

behaviors thus contributes to the mathematical and statistical difficulty of studying complex systems because of the number of variables involved.

Dynamics

Dynamics is the second theme identified in the ABM studies and is defined here as conditions that change in a sequence (Holland, 1998). ABM's are dynamic models used to represent dynamic processes. ABM's allow animation for the visualization of movement through space over time, an effective means of communicating model information (North & Macal, 2007). The analysis of process simulations occurs intuitively, qualitatively and statistically. Virtual experiments, while not equivalent to real world data, contribute to the explanatory power of dynamic models. The ability to represent and manipulate time scales, (e.g. minutes, years, decades) via simulation, allows researchers to explain phenomena that occur over a period of hours or days, such as the human inflammatory response (An, 2001), as well as those processes that happen over a period of decades such as reforestation (Manson & Evans, 2007) or climate change (Berman, Nicolson, Kofinas, Tetlichi, & Martin, 2004; Lempert, 2002).

Spatial movement is an example of a dynamic process, defined as a change in location over time. Movement can occur both geographically and virtually in a network space. Both are relevant in social processes. Agent-based epidemiologic studies of infectious diseases provide examples of how the movement of agents to various physical locations such as work places and schools contributes to contagion. Likewise, the removal of agents from the social network structure, such as a family, via death or isolation is also an important factor in the spread of disease (Burke et al., 2006; Eidelson

& Lustick, 2004; Eubank et al., 2004). Dynamic, or changing conditions, are often difficult to represent in static models and are frequently cited as a reason for using ABM.

Adaptation

Adaptation is a third recurrent theme in studies that have used ABM as a methodological tool. Agents interact with each other and with their environment. Adaptation refers to the ability of agents to learn from their interactions with their environment (which includes other adaptive agents) and change their behavior as a result (Holland, 1995). According to Holland (1995) agent behavior is determined by rules. One simple type of rule is the stimulus-response rule (e.g. IF X happens, THEN do Y). The performance of the rules over time leads to agent experience and an assessment of the rule's usefulness. Since agents may have a number of competing rules, experience aand changing assessments can result in the selection of the more favorable rule for use. New rules can also be developed, for example by combining individual components of various old rules in new ways. This process of creating new rules is described by Holland in terms of genetics. Genetic Algorithms is the term used to describe the complex process used by agents to adaptively develop behavior rules.

Axelrod's (1997, 2006b) influential work about the way in which cooperation among agents evolves, provides explanations of the way in which an agent's development of favorable strategic actions, based on the behavior of other agents over time, produces mutually advantageous cooperation. In the well-known game of "Prisoner's Dilemma," in which two individuals engaged in criminal activity are taken prisoner and separated. Each person must make a decision to either cooperate or defect. The dilemma results from the possible outcomes from the situation. Defection yields the

highest individual payoff, but only if the other prisoner cooperates. The two are both better off if they each cooperate. Two defectors is the worst case scenario. Axelrod's work demonstrates that cooperation emerges when individuals are likely to have a continued relationship and therefore have a stake in the interaction. Successful strategies for dealing with the dilemma evolve when the players avoid conflict by cooperating unless provoked by the other player's defection, forgiving provocation and exhibiting clear behavior patterns. Consistent behavior allows for adaptation to the behavior by the other player over time (Axelrod, 2006b). Other lines of research use various forms of learning theory as an alternative to the evolutionary approach to adaptation (Conte, 2002; Macy & Flache, 2002).

Emergence

Emergence, a fourth recurrent theme, is defined as the process whereby the local or micro interactions of agents with each other, and their environment, results in outcomes to the macro environment in the form of recurrent and recognizable patterns (Holland, 1998). The use of an ABM to explain the multi level phenomenon of a "standing ovation" illustrates emergence and related complex systems concepts. Although at first glance, a standing ovation seems simple, developing a representational model includes addressing issues of individual heterogeneity in terms of preference and decision-making, the influence of social interaction and learning, the agent seating location and the timing of events as the actions of individuals result in a phenomenon defined by a group. The standing ovation example illustrates the many factors that affect the emergence of a phenomenon (Miller & Page, 2004).

The ability of the researcher to actually generate a given phenomenon using ABM simulation provides significant evidence of a theory's explanatory power (Epstein, 1999). A multidisciplinary research project designed to explain the disappearance of the Anasazi civilization from the Southwestern United States illustrates this concept. Although originally believed to be the result of environmental factors, increasingly detailed models indicate that while the simulation-generated results were similar to the archaeological record, the environmental factors alone did not explain the phenomenon. The Anasazi project highlights the iterative nature of theory development using ABM, as the model expansion and revision continues, in an effort to identify plausible scientific explanations for the disappearance (Axtell et al., 2002; Dean et al., 2000; Epstein, 2006; Gumerman, Swedlund, Dean, & Epstein, 2003).

Bridging

The final recurrent theme identified in this analysis is the metaphorical use of the term "bridge" to describe ABM. Examples include using ABM as a bridge between specific research methods. The description of ABM as a bridge between disciplines is also used, based on the notion that certain problems are fundamental to a variety of disciplines. In addition to the themes identified above, other general issues traversing disciplinary boundaries are discussed, such as the process of diffusion of innovations or the effects of competition and cooperation. The identification of basic similarities can lead to theory building via derivation from desperate fields (Axelrod, 2006a). The development of interdisciplinary teams for addressing the problem of dealing with potential bioterrorist attacks, for example, is of interest to policy makers, public health researchers and developers and users of security technologies including vaccines.

Development of ABMs in this area has brought together content experts, end-users of technology and computer and modeling experts (Burke et al., 2006; Eidelson & Lustick, 2004; Eubank et al., 2004).

ABM is also described as a bridge linking methodologically diverse approaches to research and theory development. It is acknowledged that within social science disciplines, different researchers may approach the same problem using various quantitative, experimental methods, abstract mathematical modeling or descriptive qualitative research. According to Kollman and Page (2006), computational modeling techniques such as ABM are advantageous because they appeal to researchers from a variety of methodological perspectives. An explanation for this appeal is that the models combine mathematical rigor with contextual details in addressing core complexities relevant to specific problems in a given field.

In summary, analysis of agent-based modeling studies has resulted in the identification of the recurrent themes of heterogeneity, dynamics, adaptation, emergence and the metaphorical use of the term “bridge” to describe ABM. Not surprisingly, these themes are closely related to the attributes of complex systems.

Agent-based models viewed from philosophy of science positions

Positivism

Despite the claim that positivism is an often discredited philosophical view of science, its influence continues to be subject to discussion and debate within nursing and other disciplines (Henrickson & McKelvey, 2002; Jacox, 1986; Jacox & Webster, 1997; Reed, 1995; Suppe, 1989; Suppe & Jacox, 1985). Historically linked with empiricism, the positivist view became prominent in the early twentieth century along with the growing

influence of science at the expense of metaphysics and theology. Evolution of the concepts of observation, scientific method and reductionism, and modification of the view by logical positivist and modernist thinkers continued throughout this period (Honderich, 2005). Central tenants of logical positivism, such as the emphasis on empirical verification of sense data and objectivity, the hypothetico-deductive model of research and the goal of producing parsimonious and widely generalizable theories or laws, have all influenced nursing knowledge development (Rodgers, 2005; Whall, 1989).

Postmodernism

Postmodernism thought arose in the twentieth century, likely as a reaction to the more extreme views of positivism (Whall & Hicks, 2002). Some of the tenants of post modernism are appealing to many nurses, for example the rejection of the idea of universal truths or grand narratives, in favor of multiple meanings, the use of new methods, such as deconstruction techniques and discourse analysis to explore nursing phenomena and an increased focus on the context of the individual (Rolfe, 1999).

Criticisms of postmodernism abound and include the charge that it is overly relativistic and fragmenting (Whall & Hicks, 2002). In addition, some view postmodernism as excessively anti-science. This may be problematic because of the modification of the linear determinism, often associated with positivism, resulting from the rise of alternative, non-linear and heterogeneous assumptions developed by complexity scientists. According to Henrickson and McKelvey (2002), although the postmodernism focus on heterogeneity is important, other non-postmodernist, post-positivist influences are at work in the scientific community, for example scientific

realism, evolutionary epistemology and model centeredness (Henrickson & McKelvey, 2002)

ABM has been described as a method that does not easily fit into any one particular category or philosophic view (Parker, Manson, Janssen, Hoffmann, & Deadman, 2003). In some instances, ABM is described as reductionist because of the focus on identifying a finite number of essential features (Epstein, 1999; Heylighen, Cilliers, & Gershenson, 2007). It is possible to create single predictive models, based on deductive reasoning and validated by comparing simulation results to actual data (Bankes, Lempert, & Popper, 2002). Equally as useful, depending on the researcher's philosophy, is the prospect of exploratory models based on experimentation and inductive reasoning.

Exploration can include the development of multiple alternative models for comparison. The identification of common properties across multiple models of a phenomenon contributes to validity based on robustness (Bankes et al., 2002; Parker et al., 2003). ABM diminishes dichotomies because of the iterative model development process along a continuum ranging from the highly abstract and exploratory to the highly empirical and predictive (Miller & Page, 2007; Parker et al., 2003). The possibility of using ABM to bridge paradigmatic differences in the interest of theory development is consistent with Reed's (1995) philosophic views on knowledge development in nursing.

Neomodernism

Within nursing, Reed's (1995) neomodernist view provides a framework for a philosophic view of science that addresses problems of both modernist and postmodernist views. Reed (1995) used an evolutionary approach to develop a neomodern perspective,

proposing a continuous modification of philosophic influences on the process of nursing knowledge development. She describes how the nineteenth century empiricist philosophy that influenced Nightingale, was challenged and modified, as scientific development required a view to account for the existence of phenomena that were inferred from the empirical, but were not themselves observable. The recognition that science is not free from subjective influence contributes to the postmodern argument that empirical versus non-empirical knowledge hierarchies are invalid and also, the view that conceptual contributions to knowledge development that are not immediately empirically verifiable are valued.

Reed (1995) also argues that the postmodern rejection of metanarratives (e.g. over arching ideas such as those found in nursing's conceptual models), weakens science because it means that individuals complicit in producing the work of science, also conduct the critique of the product. As a result, there is a lack of an external standard for evaluation. According to Reed, the solution for moving beyond the individual critique is in the use of nursing metanarratives, defined as abstract ideals about nursing's perspective. By providing an external framework for evaluating and revising nursing knowledge, metanarratives serve as an interface between the domains of nursing science, philosophy and practice (Reed, 1995).

Reed (1995) discussed the view that nursing metanarratives have evolved historically, both in nursing practice and philosophy. Because of this historical evolution, modernist influences exist within nursing, but also, according to Reed, the current emphasis within nursing is on the continual revision and adaptation of knowledge (Reed, 2000). Thus, in Reed's view the conceptual models, (i.e. nursing's grand theories) remain

useful, and their application has not remained static (Fawcett, 2005; Fitzpatrick & Whall, 2005).

Reed (1995) identified metanarratives for knowledge development from philosophic ideas, such as the focus on "human developmental potential, transformational and self-transcendent capacity for health and healing and recognition of the developmental histories of persons and their contexts" (p. 78). Metanarratives identified by Reed as derived from practice considerations include "patient oriented, context sensitive, pattern focused and participatory" (p. 79). The discussion below applies these metanarratives to the themes related to ABM.

Metanarrative Examination

A next step in philosophic analysis process is a critical assessment of the themes related to ABM developed in the analysis (Whall et al., 2006). The idea that the manifestation of the process of nursing is relational, contextual and transformative is not new. Reed's (1997) conception of the nature of nursing processes draws specifically on systems theory, including the work of complexity scientists. Understanding the nature of nursing processes, Reed argues, is a substantive focus of the discipline and is therefore a central concept in the nursing metaparadigm (Reed, 1997). When viewed in this light, the themes developed in this analysis, because of their complex system and process orientation, resonate with problems of interest to nurse researchers as well as practitioners.

The congruence of the themes with metanarratives identified by Reed highlight the disciplinary fit of ABM as a useful tool for the development of nursing knowledge (Reed, 1995). An examination of the links between concepts from the metanarratives, the themes identified in the analysis and examples from nursing systems research is the next step in this philosophic analysis.

Transformational and self transcendent capacity for health and healing

Nursing systems research is concerned with the healthcare environment and its impact on the quality, safety and effectiveness of nursing care on patients. From the systems perspective, the metanarrative concept of transformation and capacity for health and healing can be thought of relative to the organization. The Institute of Medicine's report *Keeping Patient's Safe: Transforming the Work Environment of Nurses* (Page, 2004) explicitly makes recommendations for establishing and maintaining healthy organizational environments that maximize capabilities and promote patient safety. The development and evaluation of collaborative team models of care are among the recommendations for further research.

Recently, enhancing the work environment through improving teamwork and interdisciplinary communication has highlighted themes associated with ABM. For example, the heterogeneity of environmental factors is relevant for developing teamwork. The environment is important in terms of both the geographical layout of the work space and elements of the network environment such as team size, cohesiveness and stability (Kalisch & Begeny, 2005). Research on the interactive role of nurse-physician communication and its effect on the practice environment, nurse job satisfaction (Manojlovich, 2005; Manojlovich & Laschinger, 2007) and patient outcomes

(Manojlovich & DeCicco, 2007) illustrate themes consistent with ABM. Path analysis and multi-level modeling were used to explore the relationships between individual and organizational variables, factors in emergence. The researchers also stressed the importance of further assessing cause and effect relationships and sustainability factors by studying communication over time (dynamics), through longitudinal study.

Human developmental history and potential

Studies about the educational preparation of nurses illustrate this metanarrative from the systems view and are representative of the adaptation theme. The educational level of nurses has been linked with lower patient mortality (Aiken, Clarke, Cheung, Sloane, & Silber, 2003; Estabrooks, Midodzi, Cummings, Ricker, & Giovannetti, 2005). The nurse educator role, or one that facilitates the professional development of nursing staff, is a position that can and does influence efficacy of nursing care. Individuals in these roles use communication and promote behavior change associated with the use of evidenced based practices (Milner, Estabrooks, & Humphrey, 2005). The adaptive effects of interactions among individuals and environmental variables contribute to changes in behavior or outcomes.

Patient oriented

The issues of patient safety, quality of care and patient outcomes are high priorities in nursing systems research (Jones & Mark, 2005) and are consistent with the patient-focused metanarrative. The scope of interacting variables relevant to understanding the quality and effectiveness of patient care is vast and illustrates the heterogeneity theme. In addition to the educational level of nurses discussed above,

staffing levels in terms of numbers and skill mix have also been the subject of ongoing research.

A meta-analysis of 96 studies about the association of staffing levels with patient outcomes, provided support for the claim that higher staffing levels are associated with better patient outcomes (Kane, Shamliyan, Mueller, Duval, & Wilt, 2007). Kane et al (2007) addressed a number of issues related to this line of inquiry including contextual factors, non-linear results, the difficulty of assessing causality, the multi-level nature of the outcomes (individual patient or organization) and the problem of estimating the effect size based on a dose-response association.

Understanding optimal staffing conditions for safe and effective nursing care is a multifaceted and complex endeavor. The ability of managers to adapt staffing to changing patient conditions is illustrative of the adaptation and dynamic themes (Kim, Harris, Savova, Speedie, & Chute, 2007). Research that builds evidence for improving outcomes has important policy implications that transcend disciplinary boundaries. Examples include the relationship of effectiveness to cost (Titler, Dochterman et al., 2007) and workforce development (Kurtzman & Corrigan, 2007). The patient centered nature of nursing research is linked to the theme of the "bridge" metaphor via the frequent and increasing calls for interdisciplinary research. The development of strategies for successful team building in the academic arena is becoming increasingly important in nursing (Grey & Connolly, 2008; Grey & Mitchell, 2008; Weaver, 2008) and other disciplines as the role of teams on attaining positive outcomes becomes better understood (Guimera, Uzzi, Spiro, & Amaral, 2005; Wuchty, Jones, & Uzzi, 2007).

Context sensitive

Recent work in the area of contextual influences on knowledge translation illustrates the relevance of the themes of heterogeneity and emergence to research in this area. In one study, the use of hierarchical linear modeling demonstrated that factors at three levels, individual, specialty and hospital, explained variation in research utilization. The researchers recognized the importance of interactions between levels, a factor in emergence (Estabrooks, Midodzi, Cummings, & Wallin, 2007).

Among the constraints imposed by the data was an issue related to the theme of heterogeneity of environment. The issue was a lack of clear distinction between the geographical environment or patient care unit and the definition of the mid-level organization, by the process of self-identification as a member of a clinical specialty group. As a result, the level definitions are an example of a using a virtual network environment (the clinical specialty group) in combination with the geographic location definition at the hospital level to compare factors in research utilization.

The theme of heterogeneity was also implicated in another study which used structural equation modeling to develop and test a theoretical model of organizational influence on research utilization (Cummings, Estabrooks, Midodzi, Wallin, & Hayduk, 2007). The researchers pointed out the potential loss of precision resulting from summing subscales, or means of variables, resulting in a loss of information, in order to construct a single indicator in the study.

Critique of these works by other researchers engaged in the field of knowledge translation, praised the effort while at the same time raised a number of issues similar to those posed by researchers engaged in ABM. Among the issues cited were the need for

theory development, the recognition of philosophic differences and the use of multi-method approaches (Rycroft-Malone, 2007). In addition to design and measurement issues, (Titler, Everett, & Adams, 2007) the importance of organizational factors, including multi-level influences (Sales, 2007), and the importance and influence of multiple actors and their relationships, to the process of knowledge translation were identified as problems that require further, interdisciplinary attention (Dopson, 2007).

Pattern focused

The pattern focused nature of nursing care is evident in the area of informatics research. Growth in the use of clinical information systems that collect standardized nursing data is a key precursor for knowledge discovery using data mining methods. Exploration and analysis of patterns in data is useful for linking nursing care to patient outcomes and is closely connected to the theme of emergence (Goodwin, VanDyne, Lin, & Talbert, 2003). In another example, in a study of intervention patterns, researchers explored heterogeneous care provided to unique patients in various care settings. Use of graphic representations enabled dynamic visualization, showing how the use of interventions changed over the course of hospitalization (Shever, Titler, Dochterman, Fei, & Picone, 2007). Likewise, the use of unstructured data as the foundation for the emergence, through classification of visually recognizable dynamic patterns is central to the development of new systems for disease surveillance (Freifeld, Mandl, Reis, & Brownstein, 2008).

In summary, examples from nursing systems research demonstrate the links between each of the identified recurrent themes to important nursing metanarratives. Like other social science disciplines, researchers in nursing are engaged in studying problems

that are characterized by the presence of multiple, heterogeneous agents, dynamically interacting with each other and embedded within various contexts. These characteristics pose significant methodological issues, addressed using a variety of research designs, both qualitative and quantitative. The congruence of ABM themes with nursing metanarratives suggests that it may be useful to add ABM to the research methods currently in use.

Within nursing, Effken et al's (2003) multidisciplinary modeling study about the impact of workplace characteristics on patient safety outcomes exemplifies the methodological challenges associated with dynamic systems and the need for multi-level analysis of data. These challenges motivated the use of computational modeling in the study. The Effken et al model was constructed using data from a previous nursing study to create virtual patient care units. The model included individual and unit characteristics and took individual learning or adaptation into account. Using simulation experiments, the researchers successfully generated virtual units that matched actual unit performance. The aim of the work was to generate strategies for improving patient safety. This work illustrates the utility of ABM for creating predictive models and the iterative process of increasing specification of parameters to achieve this goal (Effken et al., 2003).

Conclusions

This philosophic analysis of ABM presents an argument for the expanded use of ABM as a theory development tool in nursing. The recurrent themes identified in the analysis are congruent with philosophic views and metanarratives in nursing. In the landmark Institute of Medicine report *Crossing the Quality Chasm: A new health system for the 21st century* (2001), the health care industry was challenged to develop a complex

systems approach to understanding and solving system problems. ABM, one of the primary tools used to study complex systems, may also be a useful addition to methodology in nursing. ABM is a promising tool for expanding the theoretical base for nursing administration and health systems.

The focus of this study was upon the utility of ABM for theory development generally. As the discipline of nursing becomes familiar with ABM and simulations, specific techniques for development such as theory or hypothesis testing may prove useful. As the use of ABM becomes more frequent in the social sciences, including nursing, the advantages and limitations of its use will be debated and clarified.

References

Aiken, L. H., Clarke, S. P., Cheung, R. B., Sloane, D. M., & Silber, J. H. (2003). Educational levels of hospital nurses and surgical patient mortality. *JAMA, 290*(12), 1617-1623.

An, G. (2001). Agent-based computer simulation and sirs: building a bridge between basic science and clinical trials. *Shock, 16*(4), 266-273.

Axelrod, R. M. (1997). *The complexity of cooperation : agent-based models of competition and collaboration*. Princeton, NJ: Princeton University Press.

Axelrod, R. M. (2006a). Agent based modeling as a bridge between disciplines. *Handbook of Computational Economics, Vol 2, 13*, 1565-1584.

Axelrod, R. M. (2006b). *The evolution of cooperation* (Rev. ed.). New York: Basic Books.

Axtell, R. L., Epstein, J. M., Dean, J. S., Gumerman, G. J., Swedlund, A. C., Harburger, J., et al. (2002). Population Growth and Collapse in a Multiagent Model of the Kayenta Anasazi in Long House Valley. *Proceedings of the National Academy of Sciences of the United States of America, 99*(10), 7275-7279.

Bankes, S. C. (2002a). Agent-Based Modeling: A Revolution? *Proceedings of the National Academy of Sciences of the United States of America, 99*(10), 7199-7200.

Bankes, S. C. (2002b). Tools and Techniques for Developing Policies for Complex and Uncertain Systems. *Proceedings of the National Academy of Sciences of the United States of America, 99*(10), 7263-7266.

Bankes, S. C., Lempert, R., & Popper, S. (2002). Making computational social science effective - Epistemology, methodology, and technology. *Social Science Computer Review, 20*(4), 377-388.

Berman, M., Nicolson, C., Kofinas, G., Tetlichi, J., & Martin, S. (2004). Adaptation and sustainability in a small Arctic community: Results of an agent-based simulation model. *Arctic, 57*(4), 401-414.

Bonabeau, E. (2002). Agent-based modeling: methods and techniques for simulating human systems. *Proceedings of the National Academy of Sciences of the United States of America, 99 Suppl 3*, 7280-7287.

Burke, D. S., Epstein, J. M., Cummings, D. A., Parker, J. I., Cline, K. C., Singa, R. M., et al. (2006). Individual-based computational modeling of smallpox epidemic control strategies. *Academic Emergency Medicine, 13*(11), 1142-1149.

Chaffee, M. W., & McNeill, M. M. (2007). A model of nursing as a complex adaptive system. *Nursing Outlook, 55*(5), 232-241.

Christakis, N.A. & Fowler, J.H. (2007). The spread of obesity in a large social network over 32 years. *New England Journal of Medicine, 357* (4), 370-379.

Christakis, N.A. & Fowler, J.H. (2008). The collective dynamics of smoking in a large social network. *New England Journal of Medicine, 358* (21), 2249-2258.

Clancy, T. R. (2004). Navigating in a complex nursing world. *Journal of Nursing Administration, 34*(6), 274-282.

Conte, R. (2002). Agent-Based Modeling for Understanding Social Intelligence. *Proceedings of the National Academy of Sciences of the United States of America, 99*(10), 7189-7190.

Cummings, G. G., Estabrooks, C. A., Midodzi, W. K., Wallin, L., & Hayduk, L. (2007). Influence of organizational characteristics and context on research utilization. *Nursing Research, 56*(4 Suppl), S24-39.

Dean, J. S., Gumerman, G. J., Epstein, J. M., Axtell, R. L., Swedlund, A. C., Parker, M. T., et al. (2000). Understanding anasazi culture change through agent-based modeling. *Dynamics in human and primate societies: Agent-based modeling of social and spatial processes*, 179-205.

Dopson, S. (2007). A view from organizational studies. *Nursing Research, 56*(4 Suppl), S72-77.

Effken, J. A., Brewer, B. B., Patil, A., Lamb, G. S., Verran, J. A., & Carley, K. M. (2003). Using computational modeling to transform nursing data into actionable information. *Journal of Biomedical Informatics, 36*(4-5), 351-361.

Eidelson, B. M., & Lustick, I. (2004). VIR-POX: An agent-based analysis of smallpox preparedness and response policy. *Jasss-the Journal of Artificial Societies and Social Simulation, 7*(3).

Ellis, R. (1983). Philosophic inquiry. *Annual Review of Nursing Research, 1*, 211-228.

Epstein, J. M. (1999). Agent-based computational models and generative social science. *Complexity, 4*(5), 41-60.

Epstein, J. M. (2002). Modeling Civil Violence: An Agent-Based Computational Approach. *Proceedings of the National Academy of Sciences of the United States of America, 99*(10), 7243-7250.

Epstein, J. M. (2006). *Generative social science: Studies in agent-based computational modeling*. Princeton, New Jersey: Princeton University Press.

Estabrooks, C. A., Midodzi, W. K., Cummings, G. G., Ricker, K. L., & Giovannetti, P. (2005). The impact of hospital nursing characteristics on 30-day mortality. *Nursing Research, 54*(2), 74-84.

Estabrooks, C. A., Midodzi, W. K., Cummings, G. G., & Wallin, L. (2007). Predicting research use in nursing organizations: a multilevel analysis. *Nursing Research, 56*(4 Suppl), S7-23.

Eubank, S., Guclu, H., Kumar, V. S., Marathe, M. V., Srinivasan, A., Toroczkai, Z., et al. (2004). Modelling disease outbreaks in realistic urban social networks. *Nature, 429*(6988), 180-184.

Fawcett, J. (2005). *Contemporary nursing knowledge: Analysis and evaluation of nursing models an theories* (Second ed.). Philadelphia: F.A. Davis Company.

Fitzpatrick, J. J., & Whall, A. L. (2005). *Conceptual models of nursing: Analysis and Application* (Fourth ed.). Upper Saddle River, New Jersey: Pearson Prentice Hall.

Freifeld, C. C., Mandl, K. D., Reis, B. Y., & Brownstein, J. S. (2008). HealthMap: global infectious disease monitoring through automated classification and visualization of Internet media reports. *Journal of the American Medical Informatics Association, 15*(2), 150-157.

Gilbert, N., & Bankes, S. (2002). Platforms and Methods for Agent-Based Modeling. *Proceedings of the National Academy of Sciences of the United States of America, 99*(10), 7197-7198.

Goodwin, L., VanDyne, M., Lin, S., & Talbert, S. (2003). Data mining issues and opportunities for building nursing knowledge. *Journal of Biomedical Inform, 36*(4-5), 379-388.

Gorman, D. M., Mezic, J., Mezic, I., & Gruenewald, P. J. (2006). Agent-based modeling of drinking behavior: A preliminary model and potential applications to theory and practice. *American Journal of Public Health, 96,* 2055-2060.

Greenhalgh, T., & Peacock, R. (2005). Effectiveness and efficiency of search methods in systematic reviews of complex evidence: audit of primary sources. *BMJ, 331*(7524), 1064-1065.

Greenhalgh, T., Robert, G., Bate, P., McFarlane, F., & Kyriakidou, O. (2005). *Diffusion of Innovations In Health Service Organisations: A Systematic Literature Review*. Oxford: Blackwell Publishing Ltd.

Greenhalgh, T., Robert, G., Macfarlane, F., Bate, P., Kyriakidou, O., & Peacock, R. (2005). Storylines of research in diffusion of innovation: a meta-narrative approach to systematic review. *Social Science and Medicine, 61*(2), 417-430.

Grey, M., & Connolly, C. A. (2008). "Coming together, keeping together, working together": interdisciplinary to transdisciplinary research and nursing. *Nursing Outlook, 56*(3), 102-107.

Grey, M., & Mitchell, P. H. (2008). Guest editorial: nursing and interdisciplinary research. *Nursing Outlook, 56*(3), 95-96.

Grim, P. (2004). Computational modeling as philosophical method. In L. Floridi (Ed.), *The Blackwell guide to the philosophy of computing and information* (pp. 337-349). Malden, MA: Blackwell Publishing.

Guimera, R., Uzzi, B., Spiro, J., & Amaral, L. A. (2005). Team assembly mechanisms determine collaboration network structure and team performance. *Science, 308*(5722), 697-702.

Gumerman, G. J., Swedlund, A. C., Dean, J. S., & Epstein, J. M. (2003). The evolution of social behavior in the prehistoric American Southwest. *Artificial Life, 9*(4), 435-444.

Henrickson, L., & McKelvey, B. (2002). Foundations of "new" social science: Institutional legitimacy from philosophy, complexity science, postmodernism, and agent-based modeling. *Proceedings of the National Academy of Sciences of the United States of America, 99*, 7288-7295.

Heylighen, F., Cilliers, P., & Gershenson, C. (2007). Philosophy and complexity. In J. Bogg & R. Geyer (Eds.), *Complexity, science and society* (pp. 117-134). New York: Radcliffe Publishing.

Holden, L. M. (2005). Complex adaptive systems: concept analysis. *Journal of Advanced Nursing, 52*(6), 651-657.

Holland, J. H. (1995). *Hidden Order: How adaptation builds complexity*. New York: Basic Books.

Holland, J. H. (1998). *Emergence: From chaos to order*. New York: Basic Books.

Honderich, T. (Ed.). (2005). *The Oxford companion to philosophy* (Second ed.). New York: Oxford University Press.

Institute of Medicine Committee on Quality of Health Care in America. (2001). *Crossing the quality chasm: A new health system for the 21st century*. Washington, DC: National Academies Press.

Jacox, A. (1986). The coming of age of nursing research. *Nursing Outlook, 34*(6), 276-281.

Jacox, A., & Webster, G. (1997). Competing theories of science. In L. H. Nicoll (Ed.), *Perspectives on nursing theory* (Third ed., pp. 423-431). Philadelphia: Lippincott.

Jones, C. B., & Mark, B. A. (2005). The intersection of nursing and health services research: an agenda to guide future research. *Nursing Outlook, 53*(6), 324-332.

Kalisch, B. J., & Begeny, S. M. (2005). Improving nursing unit teamwork. *Journal of Nursing Administration, 35*(12), 550-556.

Kane, R. L., Shamliyan, T. A., Mueller, C., Duval, S., & Wilt, T. J. (2007). The association of registered nurse staffing levels and patient outcomes: systematic review and meta-analysis. *Medical Care, 45*(12), 1195-1204.

Kim, H., Harris, M. R., Savova, G. K., Speedie, S. M., & Chute, C. G. (2007). Toward near real-time acuity estimation: a feasibility study. *Nursing Research, 56*(4), 288-294.

Kollman, K., & Page, S. E. (2006). Computational methods and models of politics. *Handbook of Computational Economics, Vol 2, 13*, 1433-1463.

Kurtzman, E. T., & Corrigan, J. M. (2007). Measuring the contribution of nursing to quality, patient safety, and health care outcomes. *Policy Politics and Nursing Practice, 8*(1), 20-36.

Kuznar, L. A. (2006). High-fidelity computational social science in anthropology - Prospects for developing a comparative framework. *Social Science Computer Review, 24*(1), 15-29.

Kuznar, L. A. (2007). Ensemble computing in agent-based modeling for transcending paradigmatic boundaries in decision theory--understanding tribal politics. In M. J. North, C. M. Macal & D. L. Sallach (Eds.), *Proceedings of the Agent 2007 Conference on Complex Interaction and Social Emergence, Co-sponsored by Argonne National Laboratory and Northwestern University, November 15-17* (pp. 433-441). Evanston, Illinois.

Lempert, R. J. (2002). A New Decision Sciences for Complex Systems. *Proceedings of the National Academy of Sciences of the United States of America, 99*(10), 7309-7313.

Macy, M. W., & Flache, A. (2002). Learning Dynamics in Social Dilemmas. *Proceedings of the National Academy of Sciences of the United States of America, 99*(10), 7229-7236.

Macy, M.W., & Willer, R. (2002). From factors to actors: Computational sociology and agent-based modeling. *Annual Review of Sociology 28*, 143-166.

Manojlovich, M. (2005). Linking the practice environment to nurses' job satisfaction through nurse-physician communication. *Journal of Nursing Scholarship, 37*(4), 367-373.

Manojlovich, M., & DeCicco, B. (2007). Healthy work environments, nurse-physician communication, and patients' outcomes. *American Journal of Critical Care, 16*(6), 536-543.

Manojlovich, M., & Laschinger, H. (2007). The Nursing Worklife Model: extending and refining a new theory. *Journal of Nursing Management, 15*(3), 256-263.

Manson, S. M., & Evans, T. (2007). Agent-based modeling of deforestation in southern Yucatan, Mexico, and reforestation in the Midwest United States. *Proceedings of the National Academy of Sciences of the United States of America, 104*(52), 20678-20683.

Miller, J. H., & Page, S. E. (2004). The standing ovation problem. *Complexity, 9*(5), 8-16.
Miller, J. H., & Page, S. E. (2007). *Complex Adaptive Systems: An introduction to computational models of social life*. Princeton: Princeton University Press.
Milner, F. M., Estabrooks, C. A., & Humphrey, C. (2005). Clinical nurse educators as agents for change: increasing research utilization. *International Journal of Nursing Studies, 42*(8), 899-914.
North, M. J., & Macal, C. M. (2007). *Managing business complexity: Discovering strategic solutions with agent based modeling and simulation*. New York: Oxford University Press.
Page, A. (Ed.). (2004). *Keeping patients safe: transforming the work environment of nurses*. Washington, DC: National Academies Press.
Parker, D. C., Manson, S. M., Janssen, M. A., Hoffmann, M. J., & Deadman, P. (2003). Multi-agent systems for the simulation of land-use and land-cover change: A review. *Annals of the Association of American Geographers, 93*(2), 314-337.
Reed, P. G. (1995). A treatise on nursing knowledge development for the 21st century: beyond postmodernism. *ANS Advances in Nursing Science, 17*(3), 70-84.
Reed, P. G. (1997). Nursing: the ontology of the discipline. *Nursing Science Quarterly, 10*(2), 76-79.
Reed, P. G. (2000). Nursing reformation: historical reflections and philosophic foundations. *Nursing Science Quarterly, 13*(2), 129-133; discussion 134-126.
Rodgers, B. L. (2005). *Developing nursing knowledge : philosophical traditions and influences*. Philadelphia: Lippincott Williams & Wilkins.
Rolfe, G. (1999). The pleasure of the bottomless: postmodernism, chaos and paradigm shifts. *Nurse Education Today, 19*(8), 668-672.
Rousseau, D., & Van der Veen, A. M. (2005). The emergence of a shared identity - An agent-based computer simulation of idea diffusion. *Journal of Conflict Resolution, 49*(5), 686-712.
Rycroft-Malone, J. (2007). Theory and knowledge translation: setting some coordinates. *Nursing Research, 56*(4 Suppl), S78-85.
Sales, A. E. (2007). A view from health services research and outcomes measurement. *Nursing Research, 56*(4 Suppl), S67-71.
Shever, L. L., Titler, M., Dochterman, J., Fei, Q., & Picone, D. M. (2007). Patterns of nursing intervention use across 6 days of acute care hospitalization for three older patient populations. *International Journal of Nursing Terminologies & Classifications, 18*(1), 18-29.
Suppe, F. (1989). *The semantic conception of theories and scientific realism*. Chicago: University of Illinois Press.
Suppe, F., & Jacox, A. K. (1985). Philosophy of science and the development of nursing theory. *Annual Review of Nursing Research, 3*, 241-267.
Titler, M. G., Dochterman, J., Kim, T., Kanak, M., Shever, L., Picone, D. M., et al. (2007). Cost of care for seniors hospitalized for hip fracture and related procedures. *Nursing Outlook, 55*(1), 5-14.
Titler, M. G., Everett, L. Q., & Adams, S. (2007). Implications for implementation science. *Nursing Research, 56*(4 Suppl), S53-59.
Weaver, T. E. (2008). Enhancing multiple disciplinary teamwork. *Nursing Outlook, 56*(3), 108-114 e102.

Whall, A. L. (1989). The influence of logical positivism on nursing practice. *Image - the Journal of Nursing Scholarship, 21*(4), 243-245.
Whall, A. L., & Hicks, F. D. (2002). The unrecognized paradigm shift in nursing: implications, problems, and possibilities. *Nursing Outlook, 50*(2), 72-76.
Whall, A. L., Sinclair, M., & Parahoo, K. (2006). A philosophic analysis of Evidence-Based Nursing: recurrent themes, metanarratives, and exemplar cases. *Nursing Outlook, 54*(1), 30-35.
Wuchty, S., Jones, B. F., & Uzzi, B. (2007). The increasing dominance of teams in production of knowledge. *Science, 316*(5827), 1036-1039.

Chapter III

Nursing Opinion Leadership: A Model Derived from Philosophic Theories of Rational Belief

Chapter Abstract

Opinion leaders are informal leaders who have the ability to influence others' decisions about adopting new products, practices or ideas. In the healthcare setting, the importance of translating new research evidence into practice has lead to interest in understanding how opinion leaders could be used to speed this process. The purpose of this chapter was to contribute to opinion leader theory by clarifying basic assumptions about opinions, individual attributes of opinion leaders and the context in which they are effective. Using theory derivation methods, two philosophic theories were used as sources to develop a model of opinion leadership, described in nursing terms. Predictions about opinion leadership based on the model include the following: Nurses who are motivated to act on the strength of their opinions become a visible resource for their colleagues. The extent to which other nurses are aware of a co-worker's successful record of accomplishment in terms of acting on accurate beliefs contributes to their credibility. If a nurse is known to be credible then his or her opinion is more likely to be sought by others who are engaged in the process of revising their beliefs. The emergence of an opinion leader is to some extent based on the perceived need for them and the presence of credible individuals to fill the role.

Introduction

Today's focus on evidenced-based practice in the provision of nursing care requires that nurses be current on various types of information and able to enhance the

application of information into practical use. According to the Institute of Medicine in *Crossing the Quality Chasm* (2001), the average time it takes for the results of randomized controlled trials to reach practice application is seventeen years. Enhanced dissemination in needed. Rogers' in his influential work about the *Diffusion of Innovations* (2003), posits that identifying and using opinion leaders may help speed adoption of new practices. The purpose of this paper is to contribute to the development of opinion leadership (OL) theory within nursing by clarifying basic assumptions about opinions, individual attributes of opinion leaders and the context in which they are effective. The process used to clarify these assumptions is the construction of a nursing opinion leader model, derived from philosophical theories about belief formation.

Background

The literature concerning OL is vast, encompassing many decades of research on the topic by investigators in many diverse fields (Greenhalgh, Robert, Bate et al., 2005). Despite continued interest, gaps remain in understanding the phenomenon and a number of methodological issues have been identified. Within healthcare, a Cochrane review (2007) of 12 randomized controlled trials (RCT) using OL as an intervention strategy to change practice behaviors found that the effectiveness of OL are mixed since some of the studies did not show a significant outcome. Of the 12 studies, only one was identified as being at low risk for bias, while eight were considered high risk based on methodological issues such as the randomization process and outcome assessment. Other important limitations included a lack of clear definition of the role of the OL resulting in problems for replication and inconsistencies that make it difficult to understand the attributes of an effective OL. In addition, there is the potential for OL to change over time. Doumit et al

(2007) identified several implications for future research. The need to identify the context in which OL are more effective; studies to assess the methods of identification of OL and clarifications of the actual activities used by OL are examples (Doumit et al., 2007).

Greenhalgh et al (2005) reviewed qualitative and mixed method studies as well as RCT and concluded that OL was important to implementation projects. The characterization of an OL as emergent and informal with a lack of distinctive role boundaries was a key finding. The authors advocated using multiple methods to provide a more complete picture of a complex, multi-faceted phenomenon that is interactive with many factors, including the context (Greenhalgh, Robert, Bate et al., 2005).

Theory derivation method

The basic framework for this theory construction effort is the Theory Derivation (TD) technique described by Walker and Avant (1983, 1988, 1995, 2005). According to Walker and Avant (2005), derivation is the process of using analogies to explain or predict; it is useful for developing new theoretical insights about phenomena. In the case of OL, the aim is to develop a better understanding of the processes used by opinion leaders to revise their own beliefs and to influence the opinion of others. The intention of beginning OL model development with a clear specification of assumptions, lead to the approach used here.

The steps for TD are: 1) developing an awareness of the level of theory development in nursing; 2) reading widely in other fields in order to identify potential theories to use as the derivation source; 3) the selection of source theories for derivation; 4) the identification of useful structure and content from the source theory; 5) modification of the content and structure, for use in nursing (Walker & Avant, 2005). The

next section of this paper begins with a brief discussion of opinion leader theory in healthcare (step one of Walker and Avant theory derivation).

Bayesianism and Kitcher's (1993) theory of *The Organization of Cognitive Labor*

Familiarity with multi-disciplinary research about OL based on a preliminary qualitative study lead to the serendipitous identification of OL analogies from lectures and reading about Bayesianism related to the philosophy of science (Anderson, 2007) (Walker and Avant TD step 2). Theory selection (step 3 of Walker and Avant TD) began with examination of the philosophical roots of opinion formation. Bayesianism is a philosophic theory concerning the rational beliefs of individuals (Joyce, 2004). Likewise, Kitcher's (1993) theory of *The Organization of Cognitive Labor* (OCL) is concerned with the ways in which groups of people arrive at consensus practices via individual group members' decisions about those practices. Kitcher's theory is an effort to explain the role of the social context on the individual, (as well as the effect of the individual on the community) in the adoption of new research findings.

Both theories, Bayesianism and the Organization of Cognitive Labor (B & OCL) are normative (e.g. are not the result of empirical data), as well as abstract in nature. The development of each theory relied on the extensive use of logical argumentation and mathematical formalism as philosophic methods to explain and justify conceptual relationships. The abstract nature and formal logical justifications of B & OCL contributed to their selection as source theories since they offered a different approach for theory development (e.g. normative instead of empirical).

The fourth step in Walker and Avant's (2005) theory derivation method is to identify the useful content and structure in the source theory. To do so, an examination of

the meanings of B & OCL, as described by Joyce and Kitcher, proceeded through the identification of their concepts and relationship statements (Hardy, 1973/2004). Following this analysis, synthesis of portions of the two theories was completed.

The use of Walker and Avant's (2005) synthesis method included a comparison of the relational statements of B & OCL for conceptual similarities. Next, organization of these statements in terms of antecedents and effects was developed. Finally, the construction of a representation, in the form of a model revealed the integration of the statements from both theories (Walker & Avant, 2005).

Identification of useful structure and content

The analytic process of identifying the concepts, their meanings and relationships, within B & OCL, began with listing and defining major ideas and their definitions. The process of translating mathematical formalism into words in order to create brief summaries of the content and structure of B & OCL, resulted in the simplification and prioritization of the concepts and the relationships between them. The summaries follow with a discussion of the results of the analysis and synthesis.

Bayesianism

According to Joyce (2004), Bayesianism is a normative theory of rational belief. Rational beliefs are variable in strength, consistent with the laws of probability and can change through the process of learning (Joyce, 2004). From an epistemic standpoint, rational agents seek to maximize the accuracy of their beliefs. Practically motivated rational agents want to maximize their subjective expected utility, or determine what is in their best interest. The focus of this synopsis is on Bayesian epistemology as described by Joyce (1998, 2004, 2005).

Joyce (2004) defines a belief as an individual's estimated level of confidence in the truth-value of a proposition, expressed in probabilistic terms. Belief corresponds to the extent to which a person is willing to pre-suppose the truth of a proposition in theoretical or practical reasoning. It is not necessary to assign a specific numerical value to express the strength of a belief probabilistically (e.g. Jane believes it is improbable that X is true). Beliefs can be unconditional or conditional. An unconditional belief means that confidence is based a particular proposition, whereas a conditional belief is the expression of confidence in the truth of one proposition while supposing that other propositions are also true (e.g. X is highly probable given Y) (Joyce, 2004).

The quality of a person's belief is evaluated by the accuracy of his subjective confidence estimates relative to objective probabilities. Individuals who have high levels of confidence in the truth are rewarded because using true premises (accurate representation of the world) as a basis for reasoning, in theory produces better outcomes (Joyce, 2004). Individuals are motivated to seek accurate beliefs, and increased accuracy follows from holding beliefs that are consistent with the laws of probability (Joyce, 1998).

Joyce (2005) further describes an individual's belief as a reflection of that person's total evidence in favor of a given proposition. Total evidence is relative to the individual because it includes both prior beliefs and new knowledge gained through learning. Bayes' Theorem is a rule for calculating the probability of a person's revised belief (termed "posterior" belief) while taking into account new evidence. Bayes' Theorem relates this posterior probability of a hypothesis, which is conditional on the new information, to the ratio of the "prior" probability (e.g. prior to the new evidence) of

the hypothesis and the probability of the new information. This ratio is then multiplied by the "likelihood" of the new information given what is already known about the hypothesis (Joyce, 2004).

Joyce (2005) claims that three attributes of evidence affect beliefs in different ways. The first is balance, an assessment of the truth-value of the evidence, which either is in favor or opposed to the belief. Balance corresponds to the strength of the belief. Second, the weight or amount of evidence affects the stability of a belief, e.g. the greater the weight of the accumulated evidence, the less likely a dramatic change in belief will occur. Finally, specificity refers to the degree to which the evidence is complete or unambiguous with respect to the proposition. Specificity influences the range of potential probabilistic values of the person's state of confidence in the belief. Very specific evidence may result in a precise degree of change, whereas ambiguous evidence results in a broad range of plausible new confidence probabilities (Joyce, 2005).

Balance, weight and specificity of evidence play a role in learning, or conditioning. Conditioning is the process of adjusting a belief based on the acquisition of new evidence while taking into account the degree of effect of the prior belief in the determination of the new level of confidence. The learning process takes place in two stages. First, the new information causes a subset of beliefs to be altered. Following this experience and accounting for what he or she knows, the person will revise other opinions.

Simple conditioning is the basic model of Bayesian leaning. In this case, a person with a prior belief about a proposition X, that has a probability > 0 and < 1 (uncertainty), undergoes a learning experience where the new information causes the person to be

certain (100% probability) of X. It then follows that opinions inconsistent with X will be revised to probability = 0, and opinions consistent with X will increase in probability. Simple conditioning requires certainty, in order to adjust beliefs when the evidence is vague or imprecise, (not categorical) realistic learning involves gradated estimates of confidence (beliefs about) the new evidence as well as the gradated original belief (Joyce, 2004).

Kitcher's theory of the Organization of Cognitive Labor

Kitcher's (1993) conception of belief revision includes the effects of the social interactions of individuals on the generation of consensus practices or community wide beliefs (Kitcher, 1993). Social epistemology, according to Kitcher, is concerned with identifying the characteristics of social systems that are conducive to achieving collectively true beliefs. Communities also have practical aims, e.g. the optimal use of resources to enable best practices.

Kitcher (1993) describes the theory of OCL in terms of a community of scientists, and the ways in which the actions of individuals, in relation to the group, result in the achievement of community goals. The best community response to new scientific findings is the result of various distributions of individual effort or "cognitive labor" relative to the new evidence.

Since there is no centralized controller to assign the work, Kitcher (1993) further explains how various combinations of individual decisions and social interactions are more or less successful in the generation of an ideal distribution of effort for attaining community goals. Central issues include the effect of motives, trust, authority and diversity on belief revision. Within the context of the social structure of the community,

belief revision results from the cognitive work of scientists who, when presented with new evidence can adopt it, ignore it, or attempt to replicate it. The numbers of individuals in a community who align themselves with each of these options define the distribution of cognitive effort. Diversity means that the community is composed of individuals aligned with the various options concerning the new evidence.

Kitcher (1993) begins his discussion of OLC with an identification of the effects of authority on the knowledge development of individuals. These epistemic effects include depending on the teaching of authority figures, trusting others to decide certain issues and assessing the authority of others when making decisions regarding acceptance of the claims made by them. Among the advantages of deferring to authority are increasing the speed and feasibility of reaching goals. Borrowing, or deriving material from experts, for example, can save the individual the time and effort required to obtain the information himself. Kitcher further posits that the decision to rely on authority includes an assessment of the expertise of the authority figure relative to the agent himself, the resources available and the potential for obtaining credit by competing.

According to Kitcher (1993), the evaluation of an individual's authority rests on the assessment of the probability that what the individual says is true, or his/her credibility. The bases of an individual's credibility are the unearned authority resulting from social position, earned authority, based on performance and personal authority, based on relationships. The evaluator weights the importance each type of authority and combines them to arrive at the total authority. Kitcher claims that the differentiation between authority and credit is important. Earned authority, which results from an individual's performance, is topic relative (e.g. subject matter expertise), whereas credit

results from an overall assessment. Seeking credit can be an important practical motivator for individuals engaged in scientific research.

The connection between credit and authority is particularly evident in the case where positive performance (earned authority) results are available to others who are making their assessments. Comparing the truth-value of an authority's opinion to one's own beliefs on the topic is an important source of credit attribution. According to Kitcher (1993) when an individual is able to directly calibrate opinions in this way, it leads to a baseline decision rule that favors following the judgment of the person with higher earned authority.

Unearned authority, on the other hand, is based on factors such as title or institutional affiliation, and can result in what Kitcher labels a "prestige effect." Personal authority is sometimes considered as a dimension of unearned authority because it is based on factors such as friendship ties. The weight assigned by an individual to unearned versus earned authority is a subjective assessment influenced by the importance the individual attaches to prestige, and the opportunity available to the person for direct calibration of earned authority.

Kitcher (1993) posits that it is often the case that direct calibration may be unreliable, e.g. someone outside the specialty, or otherwise unknown to the person making the judgment introduces the new information. In these instances, indirect calibration may take place. Indirect calibration involves using the judgment of others, whom the individual believes to be knowledgeable about the source, when assessing authority.

To summarize Kitcher's major points; when a scientist is presented with new evidence, decisions about a course of action (adopt, ignore, further research) are based on epistemic goals for truth (maximize being right) and/or non-epistemic goals that maximize utility (e.g. be the first to be right). Secondly, the "authority effect" means that an individual's decisions involve an assessment of his own authority (which includes factoring in the perception of others), the authority of his information sources and the authority of his competitors. Thirdly, Kitcher posits that competition promotes diversity in a community. This is because some individuals will opt to adopt new findings, while some will determine that it is beneficial to create their own findings. Authority effects can reduce competition and therefore decrease diversity (Kitcher 1993).

Next, Kitcher addresses the question of how diversity affects the attainment of community goals using three examples; response to innovation, selection among rival experimental methods, and theory choice. In each example, the proposed optimal strategy for achieving community goals is followed by a discussion about how individual actions contribute to achieving the community goal.

The first example is that when there is an announcement of an innovative finding in a community, the best strategy for the community is the one that results in using the findings if true, rejecting them if false or delaying a decision pending further information. The extent to which consensus strategy is best depends on the probability that the finding is true. In most cases, some effort at replication is desirable.

The cost/benefit assessment related to using the resources to replicate the findings depends on the probability the finding is true, the reliability of potential replicators and the resources available. The chance that the optimal community response will arise, via

individual community member action, depends on structural factors that contribute to the presence of sufficient rewards for engaging in replication. Among these structural conditions are the extent of the competition in the community, the potential for credit attribution and the authority of potential challengers to the new findings.

Kitcher's second example is that of choosing among technical methods, the community aim is the attainment of accurate results as soon as possible. The matter of community choice between methods depends on the prospects of the success obtained given the intrinsic properties of the method. Complicating the scenario is the possibility that either of two methods could require a critical mass of users to achieve an answer about its utility. In this case, the number of community members available to use the methods is a contributing factor. In general, the community optimal is a division of individuals in which the use of both methods occurs, unless one of them is clearly superior.

Individual decisions that give rise to the community optimal result depend on the extent to which the community members are motivated by epistemic versus personal goals. In the case of an epistemically pure community, individuals base their decision strictly on the probability that one method is intrinsically better, leading to the use of only that method. Community consensus in favor of one method may be beneficial if the chosen method is clearly superior. If not, the results will be costly.

Contrast the community group composed of individuals seeking to maximize self-interest. Possibilities for reward may make it advantageous for individuals to try a less probable method in terms of intrinsic superiority. Under conditions of uncertainty about the methods, the result is a community optimal division of users. If the community is too

large, or the probability of the method's success is too low, then there may be no incentive for an individual user to switch methods.

In this example, community structures (e.g. institutions) that provide incentives for the individual attainment of non-epistemic goals are more likely to promote the optimal diversity. Another possibility is the introduction of local autocratic figures to impose method choice. The result is a solution for maintaining diversity when consensus formation based on individual decisions is suboptimal for the community.

Kitcher's final example illustrates the value of a diverse OCL related to the decision problem of theory choice. The community goal is acceptance and use of the "true theory". The basis for the presence of rival theories is the assumption that the situation is indeterminate, and that each theory has a cadre of supporters who continue to work on them. Complicating the situation is the possibility of consensus adoption of a successful theory whether it is correct or not. Theoretical development through scientific work on both theories is the baseline optimum. The potential costs of delay, in the attainment of consensus practice, factor into the determination of the optimal division of labor. If the cost of delay is low, and the probability for the development of a true and successful theory is high, it is best to delay decision. On the other hand, if the delay cost is high and imminent resolution of the actual truth-value is unlikely, consensus practice using a "somewhat successful theory" is preferred for attaining community goals.

Individual theory choice will be likely to result in the optimal community situation when the probabilities of the truth-value of each of the theories are close. An exception occurs in a scientific community in which everyone is cynical and does not

care if a theory is true, only that it appears successful. This situation leads to consensus support for a potentially false theory.

Tradition also influences individual decision-making and can blunt the effect of cynicism. For example, a community may be divided into a group that supports the currently dominant theory, another that champions the underdog theory and yet another group that is uncommitted (e.g. newcomers). If the amount of credit newcomers will obtain from defending the traditional view is low enough, there is motivation for them to work on developing an underdog theory.

Kitcher (1993) also points out that in this example; his idealized theory choice scenario relies on two homogeneous assumptions about individuals. The first assumption is that either epistemic goals or expected utility goals drive an individual's motivation. The second is that all of the individuals assign the same probabilities to the theories as everyone else in the community. The introduction of heterogeneity, to one of these factors separately, promotes cognitive diversity. When both heterogeneous motives and belief are considered together, the effect of heterogeneity is, according to Kitcher, an interaction effect in which the two factors can cancel each other out.

After concluding the discussion of the three examples, Kitcher (1993) elaborates on an overall assumption, that of the various processes of consensus formation. Considerations that affect the costs and benefits of the process determine the consensus formation mechanism that serves a community best. First, the maintenance of a consensus practice depends on the number of individuals who make that decision (e.g., a dictator imposes the practice versus a situation in which all community members must individually decide in favor of a practice). The probability of appropriate modification of

consensus practice is to some extent a function of the total level of authority in the community over the number of independent decision makers. If maintaining stability is the aim, then a higher number of decision makers is beneficial.

The balance of a high number of individual decision makers against the potential opportunity costs can reduce the desirability of multiple decision makers. If the diversion of enough people from works that would benefit the entire community occurs, for example by pursuing the replication strategy, then the distribution becomes costly. On the other hand, reducing the number of decision-makers can result in the possibility of alienating members of the community who do not agree with an imposed consensus practice.

In concluding discussions, Kitcher summarized his theory by claiming first, that non-epistemic motives contribute to the scientific community's epistemic goals by promoting diversity. Secondly, the effect of factors such as authority depends on the contextual variables including the social situation and the decision problem itself. The process of progressive change in consensus practice involves complex, individual reasoning efforts refined by the social situation. The combination of individual and social factors results in various distributions of cognitive effort. Understanding the effect of these distributions on community outcomes is essential for developing effective community strategies for advancing knowledge (Kitcher, 1993).

Analysis, synthesis and model creation

To summarize thus far, the theories selected in step three of Walker and Avant's (2005) TD process, were analyzed for content and structure. Bayesianism provides an account of individual beliefs and their revision, given new evidence. Kitcher's (1993)

theory of *The Organization of Cognitive Labor* explains the relationship between individual beliefs, the role of authority and the formation of consensus practice in a community. The process of identifying concepts, statements and relationships was iterative and often concurrent with synthesis, or combining the elements into a single model.

Analysis

Initially, the process of analyzing each of the theories individually leads to the identification of major concepts and relational statements. Wording the relational statements in the form of "If/then" relationships further aided identification and clarification of concepts from B & OCL.

Synthesis

Following individual identification, the concepts from each theory were combined and then time ordered, based on the theoretical processes. The provisional placement of the relational statements from each theory under the combined conceptual headings resulted in a master list of statements. Comparison of the relational statements, removal of duplicates and reordering by sequence and level of abstraction resulted in 9 concepts and 78 statements.

Further clarification of the concept definitions resulted from the iterative process of working with the statements. All of the nine concepts are variable and most are multi-dimensional. Table 1 presents the concepts, their major dimensions and examples of their multi-level meanings.

When defining concepts, it is important to recognize differences in terminology among and within theories. For example, the terms "belief" and "opinion" were used

interchangeably and are considered synonymous here. The concept of “evidence” encompasses actual evidence, new information, new practices and new findings. Pragmatic motives were also labeled “practical”, “personal” and “sullied”. Credit, or credibility, is the outcome of the attribution of authority and was used interchangeably to mean “total authority”. Finally, the concept “learning” is also known as “conditioning”, “updating”, or “revising” beliefs.

After clarification of the concepts, the next step was further analysis of the 78 relational statements in terms of the nature of the relation as defined by Hardy (1973/2004). The majority were probabilistic (If A, then probably B). Many were also conditional (If A, then probably B, but only if C). Structural assessment of the concepts and relational statements revealed the presence of connections among all of the concepts, either directly or conditionally. The few relationships between the concepts that were not specifically derived from the analysis can be theoretically deduced from the others (e.g. via time ordering).

Model creation

The final phase of the content and structure selection step of TD is the construction of a synthesized model. Figure 1 shows the overall model, depicting belief revision within the context of a community. Figures 2 and 3 depict the expanded versions of processes in the overall model (e.g. assessing new evidence and credibility, and updating beliefs.

Description in nursing terms

The final step in Walker and Avant’s (2005) TD procedure is the modification of the content and structures of the theory for use in nursing. Initial structural modification

occurred via the synthesis of concepts and relational statements. The description of the resulting abstract model in nursing terms explicates its usefulness for the discipline. The following scenario illustrates the model in the context of a hospital setting (community). Within the hospital are several patient care units defined by a medical specialty (communities). Each unit has a manager, a clinical specialist, and staff nurses with a range of nursing experience.

Nursing OL example:

> To begin the process, Jane, the clinical specialist on the stroke unit attends a hospital wide meeting. At the meeting, Nancy, the clinical specialist from the orthopedic unit, presents information about a new nursing intervention to prevent pressure ulcers in immobilized patients (obtains new evidence). Initially, Jane is not really sure that the new intervention is much of an improvement over current practice (direct calibration of content), but her friend Nancy seemed enthusiastic and, it seems to Jane, usually knows what she is talking about (direct calibration of source, attribution of personal and earned authority) even though she is in a different specialty area (specificity). Jane is still uncertain about the new information; however, because of the renewed demands to reduce the occurrence of pressure ulcers resulting from new Medicare regulations, (motives) and since her meeting with the manager was cancelled at the last minute, Jane decides to use the time (resources) to find out more about the intervention (investigate further).
>
> Jane looks up the original research report and discovers that the study was a randomized controlled trial conducted at an eminent university by well-known researchers in the field (assess content and source of evidence). In light of what she found, Jane reassesses the evidence, determines that it is reliable and revises her opinion such that she is now strongly convinced that the new intervention is the best practice for preventing pressure sores. Given the potential benefit to immobilized patients on the unit and the kudos Jane will get for reducing the incidence of pressure ulcers on the unit, she requests time on the agenda at the next staff meeting (motives, action). At the meeting, Jane enthusiastically voices her opinion that she and everyone on the unit should adopt the new practice (visibility, change in consensus about practice).
>
> At this point, the process of belief change for one individual is complete. The question of whether or not Jane becomes an opinion leader is dynamic and

depends on multiple repetitions of the process among other nurses on the unit. Will Jane influence the rest of the staff to adopt the new intervention? How might she contribute to the decisions other's make? What are some of the contextual factors that affect her influence?

First, by announcing her belief in the new intervention at the staff meeting, Jane's views became visible to the rest of the nursing staff and second, she introduced new information about the nursing intervention. Staff members on the unit will now begin the belief revision process by assessing this new information, based on what they already know (prior beliefs) about pressure ulcer prevention, (content) and their assessment of Jane's credibility (source). Because Jane made her opinion known, nurses can compare their own beliefs with hers (direct calibration, earned authority). In addition, Jane's previous record of giving sound patient care advice (earned authority) and her position as a clinical specialist (unearned authority) contribute to her credibility among the staff. Some of the new graduate nurses had learned about the new intervention in school, although they were not very confident about it since no one on the unit used it (strength of belief, action).

This knowledge, combined with their belief in Jane as a credible source led them to adopt the new information about the intervention and revise their own opinion. A number of the newcomers became convinced that the new intervention was a very good idea and visibly changed their own practice to incorporate the new intervention. This resulted in a change to the consensus practice on the unit. Others, although their opinions changed somewhat, were not quite convinced enough to put the new intervention into practice yet and kept their opinions to themselves.

Several of the more experienced nurses had a different reaction to the proposed new intervention. The intervention that was currently the consensus practice had worked perfectly fine over the years (strength and weight of belief). The new intervention did not seem likely to improve things that much (content) and furthermore, Jane had not actually taken care of a patient in months (source). In fact, they believed, it was nothing new at all, and so ignored the information.

Other nurses were less certain about the evidence for the new intervention. A number of them, although citing a lack of time, (resources) thought that there was some potential for an improvement in patient care (motives). Rather than check the evidence themselves, they asked other nurses, believed to be credible, for their opinions about the new evidence. A few asked Jane about the credibility of her original sources (indirect calibration). Others decided to take the time to read the research report or to try out the intervention themselves before making up their minds. Armed with additional information

about the evidence, the nurses reassessed it. Several adopted it and updated their own beliefs about nursing interventions to prevent pressure ulcers. Eventually more nurses on the unit changed their practice to the new intervention, thereby revising community consensus practice.

The changing consensus on the unit pleased the manager, since even though it was taking some time; she was able to avoid imposing consensus by requiring the use of the new intervention (motives). Her public praise of Jane, for contributing to the reduction of pressure ulcers by introducing the new intervention, improved the clinical specialist's credibility among her peers. The fact that Jane acted on beliefs that turned out to be true was made even more visible by the accolades of the manager (earned authority). Soon clinical specialists from other units were asking Jane about the new intervention, expanding her influence (credible source of new evidence) and opening up new sources of information for herself (increasing resources).

The above example, although highly idealized, explains how the opinions and actions of individual nurses can affect the beliefs of others within the context of a patient care unit (Table 2). Predictions about opinion leadership based on the model concepts include the following: Nurses who are motivated to act on the strength of their opinions become a visible resource for their colleagues (beliefs, motives, visibility). The extent to which other nurses are aware of a co-worker's successful record of accomplishment in terms of acting on accurate beliefs contributes to their credibility (actions, outcomes, authority). If a nurse is known to be credible then her opinion is more likely to be sought by others who are engaged in the process of revising their beliefs (authority, learning). The emergence of an opinion leader is to some extent based on the perceived need for them and the presence of credible individuals to fill the role (resources). For example, if all of the nurses on a unit are confident in their own ability to assess new evidence, they may not seek another opinion. Alternatively, it is possible that the perception, that no one on the unit is credible on the topic, exists.

In summary, a combination of steps from Walker and Avant's (2005) methods for theory construction formed the process used to develop a model of nursing opinion leadership in this paper. These steps included selection and analysis of philosophic theories for derivation, synthesis of the theories and construction of a representative model, further developed in nursing terms. The resulting model is abstract and contains concepts that are variable and multi-dimensional. In addition, the relationships among the concepts are probabilistic and often conditional on other probabilistic relationships. When viewed as a dynamic process, the model explains how, and under what conditions, an individual who influences the opinions of others could emerge in a community. Additional insight about when and how influence on opinion formation works, may contribute to strategies designed to increase an individual's influence and therefore his effect on the adoption of evidence based practice changes in a community.

Conclusions

This model of nursing opinion leadership, developed by deriving a system of concepts and their relationships from philosophic theories, contributes to opinion leader theory by providing a normative framework for further study designed to address gaps in understanding about the contextual factors on the development and utility of opinion leader strategies. In addition to enhancing explanation and providing a basis for prediction, the model development process highlighted several factors that may make empirical testing difficult. These factors include the roles of context and multi-level interactions on the emergence of opinion leadership. In addition, the probabilistic, dynamic relationships among multi-dimensional and variable concepts pose challenges for research design as well. Future research and testing of the model will help to

determine the extent to which aspects of the model may need to be modified or further specified for use in nursing.

Figure 3.1 Synthesized model of individual and community belief revision

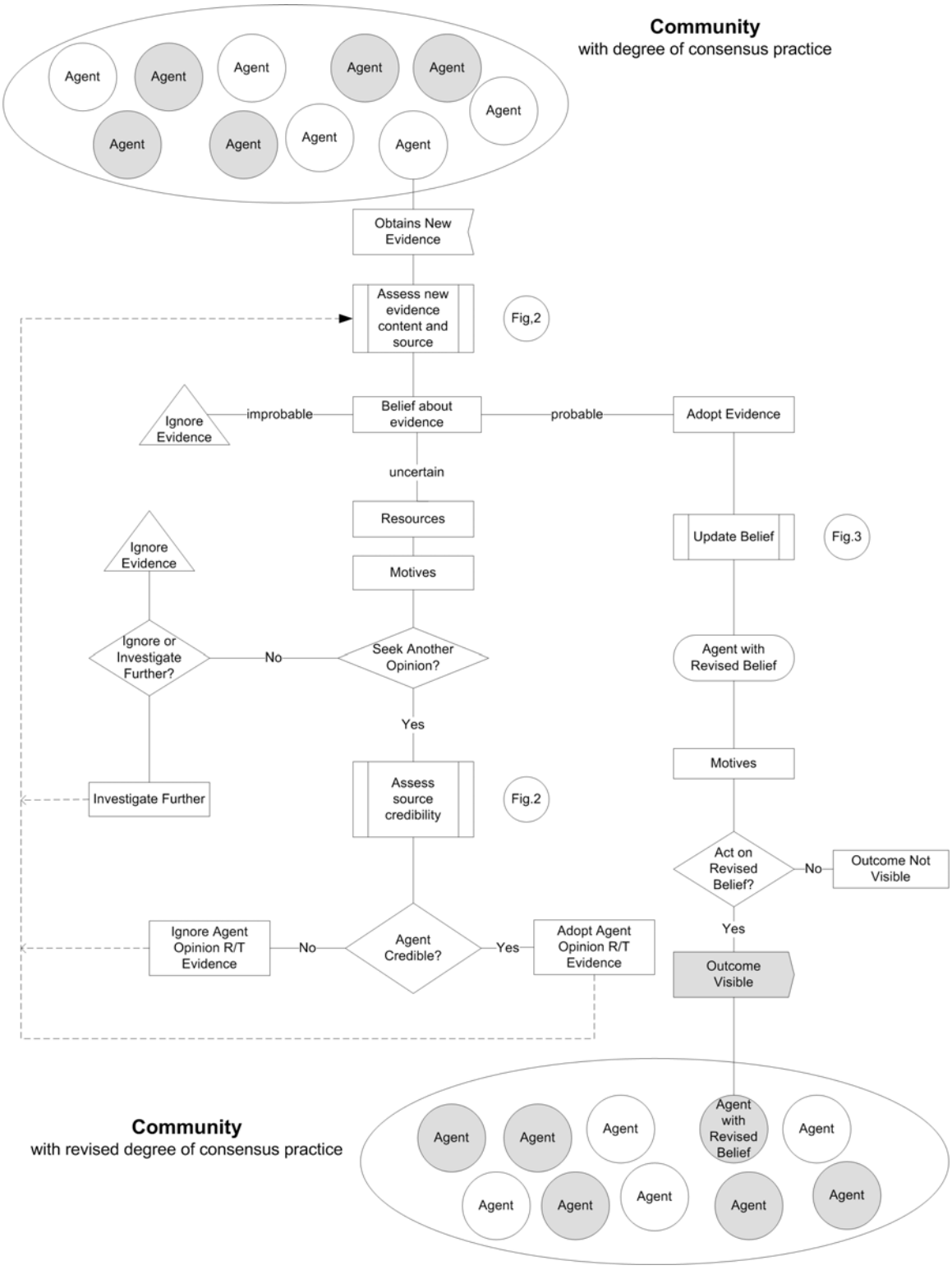

Figure 3.2 Expanded processes represented in the overall model

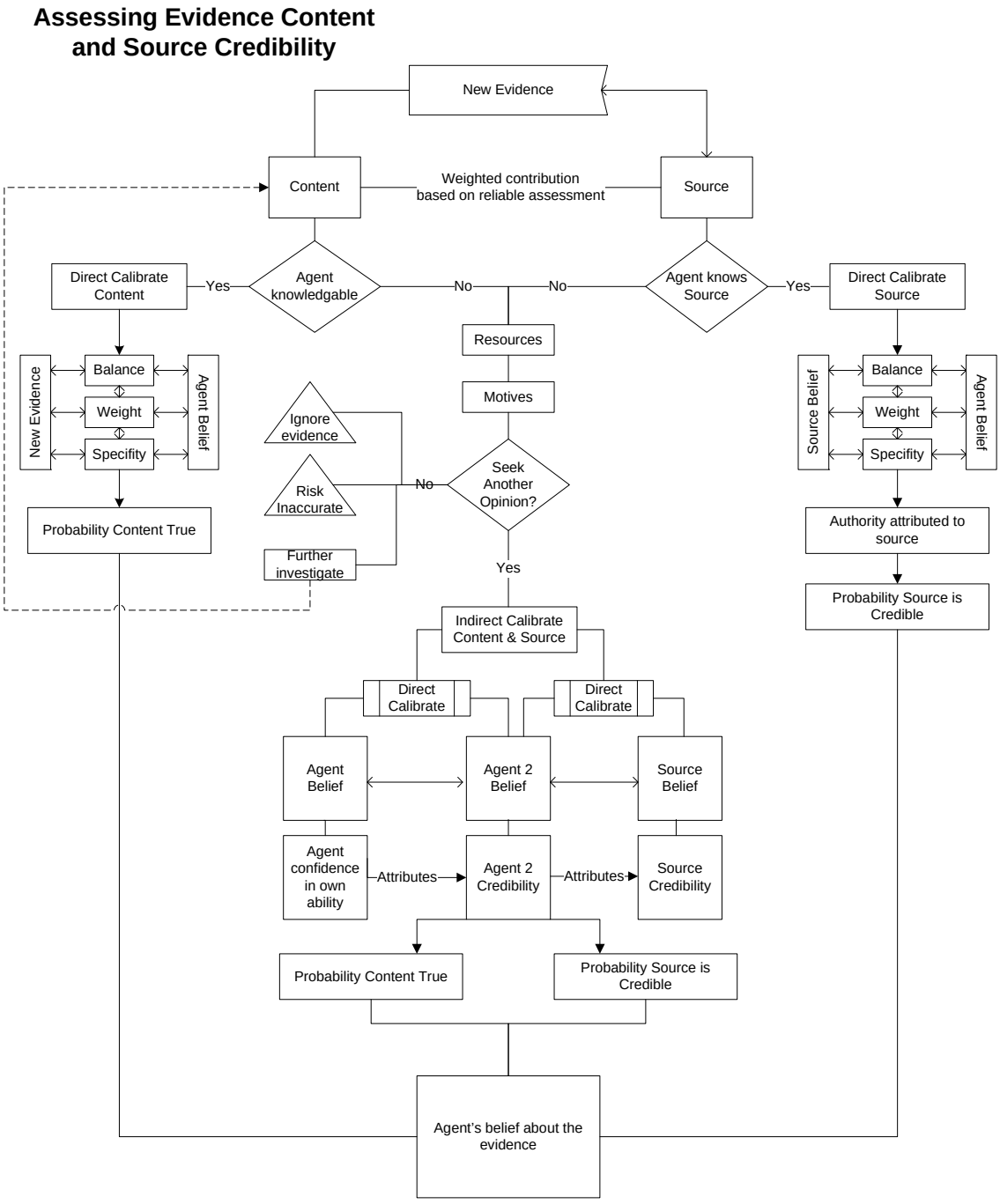

Figure 3.3 Belief revision process, expanded from the overall model

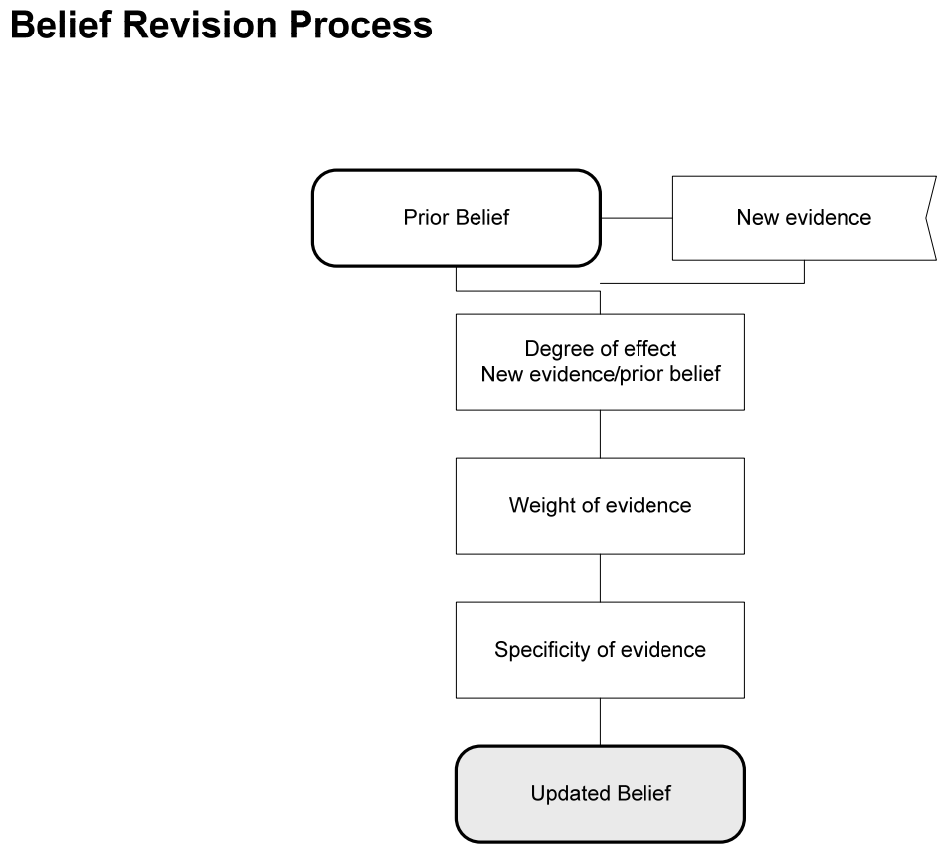

Table 3.1 Combined concepts from source theories

Concept	Individual	Community
Belief		
Strength	Gradated degree pro or con	Degree of consensus
Weight	Amount of evidence	Sum of individuals' evidence
Evidence		
Content	Probability of true facts	Probability of true facts
Source	Credibility of creator or introducer of the evidence	Credibility of creator or introducer of the evidence
Valence	Corresponds with strength of belief	Corresponds with degree of consensus practice
Weight	Individual attribution	Community attribution
Specificity	Relevance to belief	Relationship of source to community
Motives		
Epistemic	Truth, accurate beliefs	Truth, consensus practice based on fact
Pragmatic	Self interest	Community interest, using resources effectively
Resources Time Money Energy Social network	Amount of personal resources including personal connections	Availability of rewards, number of members in the community, expertise and authority of members
Visibility	Degree to which individual is aware of the presence of the other concepts.	Degree to which peers know each other's beliefs, practices, credibility or the amount of community resources
Authority Unearned Earned Personal	Subjective estimate of peers relative to self	Collective attribution
Learning	Update beliefs based on new evidence	Update distribution of cognitive labor based on evidence (number of adopters, rejecters, replicators)
Actions	Behavior of individuals	Sum of individual behaviors
Outcomes	Visibility, credibility, attainment of individual goals, change in practice	Attainment of community goals, change in degree of consensus practice

Table 3.2 Predictions about opinion leadership

How to become an opinion leader

Evaluate evidence accurately
- Increase ability to directly calibrate beliefs
- Actively clarify uncertainty
- Expand social network to increase opportunities for calibrating belief directly

Increase strength of belief

Act consistent with beliefs

Increase visibility in the community

Community members attribute credibility related to accuracy of beliefs and their alignment with outcomes (increase earned authority)

Increase availability to community members for indirect calibration purposes

Have motives that are consistent with both competition (e.g. take action, seek credit) and cooperation (e.g. sharing beliefs with others who seek opinion)

How to influence members of the community

Act as a credible source of new evidence

Act as a resource for indirect calibration for others who are assessing the content or source of new evidence.

Increase availability for direct calibration by increasing visibility

Increase visibility by acting on own beliefs (e.g. change practices, give voice to beliefs)

Community factors that affect emergence of opinion leaders

Community wide strength of belief (e.g. degree of consensus practice)

Number of agents perceived as credible (earned and unearned authority)

Incentives and resources available to agents

Weight of evidence in community

Motives of the community

Consensus forming process in the community

References

Anderson, C. A. (2007). *The Nature of Opinion Leadership in Nursing*.Unpublished manuscript.

Doumit, G., Gattellari, M., Grimshaw, J., & O'Brien, M. A. (2007). Local opinion leaders. Cochrane effective practice and organisation of care group. *Cochrane Database of Systematic Reviews, 1*.

Greenhalgh, T., Robert, G., Bate, P., McFarlane, F., & Kyriakidou, O. (2005). *Diffusion of Innovations In Health Service Organisations: A Systematic Literature Review*. Oxford: Blackwell Publishing Ltd.

Hardy, M. E. (1973/2004). Theories: Components, development, evaluation. In P. G. Reed, N. B. C. Shearer & L. H. Nicoll (Eds.), *Perspectives on nursing theory* (4th ed., pp. 75-94). Philadelphia: Lippincott Williams and Wilkins.

Institute of Medicine Committee on Quality of Health Care in America. (2001). *Crossing the quality chasm: A new health system for the 21st century*. Washington, DC: National Academies Press.

Joyce, J. M. (1998). A Nonpragmatic Vindication of Probabilism. *Philosophy of Science, 65*(4), 575-603.

Joyce, J. M. (2004). Bayesianism. In A. R. Mele & P. Rawling (Eds.), *The Oxford Handbook of Rationality*. New York: Oxford Scholarship Online. Oxford University Press. Accessed February 20, 2007at http://dx.doi.org/10.1093/0195145399.001.0001.

Joyce, J. M. (2005). How probabilities reflect evidence. *Epistemology, vol.19, Philosophical Perspectives* Retrieved February 20, 2007, from http://www.blackwell-synergy.com/doi/pdf/10.1111/j.1520-8583.2005.00058.x

Kitcher, P. (1993). The organization of cognitive labor. In *The advancement of science: Science without legend, objectivity without illusions* (pp. 303-389). New York: Oxford University Press.

Rogers, E. M. (2003). *Diffusion of Innovations* (Fifth ed.). New York: Free Press.

Walker, L. O., & Avant, K. C. (1983). *Strategies for theory construction in nursing*. Norwalk, Connecticut: Appleton-Century-Crofts.

Walker, L. O., & Avant, K. C. (1988). *Strategies for theory construction in nursing* (Second ed.). Norwalk, Connecticut: Appleton and Lange.

Walker, L. O., & Avant, K. C. (1995). *Strategies for theory construction in nursing* (Third ed.). Norwalk, Connecticut: Appleton and Lange.

Walker, L. O., & Avant, K. C. (2005). *Strategies for theory construction in nursing* (Fourth ed.). Upper Saddle River, New Jersey: Pearson-Prentice Hall.

Chapter IV

Verification and Validation of a Nursing Opinion Leader Model Using Agent-based Modeling

Chapter Abstract

The nursing opinion leader model is a normative model derived from philosophic theories of belief formation. The purpose of this study was to begin the process of verification and validation of the model using agent-based modeling and simulation (ABMS). ABMS enables the demonstration of the effects of heterogeneous individuals and their behaviors and also allows representation of the contextual and dynamic nature of phenomena like opinion leadership. The model was programmed to represent a fictitious nursing unit and the resulting simulated data was analyzed. Results indicated that the ABM is performing consistent with the theory. Nurses act on the strength of their beliefs and, if perceived as credible, become opinion resources for their colleagues who seek their advice. The degree to which a nursing unit consists of both uncertain staff members and others willing and able to share their opinion, has implications for predicting the usefulness of an opinion leader strategy for improving the adoption of evidence-based nursing practice.

Introduction

This paper reports on the application of agent-based modeling and simulation (ABMS) to a model of nursing opinion leadership. The nursing opinion leader model (NOLM) is a normative model derived from philosophic theories about belief formation. The model seeks to explain how the opinions and action of individual nurses affect the beliefs of others, and the contextual factors that contribute to nursing opinion leader

(NOL) effectiveness. NOL is a dynamic and multi-level phenomenon (Anderson, 2008). The purpose of this paper is to begin the process of verification and validation of the NOLM using ABMS. ABMS is a useful methodological tool for theory development. ABMS enables demonstration of the effects of heterogeneous individuals and their behaviors on the macro-level environment. ABMS is practically useful as part of a theory development effort because it permits the use of "simulated" data to model theorized relationships. This may lead to further elaboration of or revisions to a theory prior to the collection of actual data.

Actual data, once obtained, can then be programmed into the ABMS, and would provide an additional test of the model (North & Macal, 2007). The aims of representing both the contextual and dynamic natures of the NOLM lead to the use of this methodological tool. The programming of the basic structural elements of the model to represent a fictitious nursing unit and analysis of the resulting simulated data are described next.

The steps for examining and developing an ABMS begin with the specification and programming of agent attributes and behaviors using a software development platform. A resulting "model-program" is then executed, creating a simulation. Data obtained from the simulation can be statistically analyzed (Gilbert, 2008). The following describes creation of the NOL-ABMS using NetLogo (Wilensky, 1999). NetLogo, one of several development platforms available, was selected for use in this effort because of its "ease of use" as well as its extensive documentation.

Programming and model description

The context for the NOL-ABMS is a patient care unit with one manager and a variable number of nurse educators and staff nurses. Figure 4.1 depicts the overall sequential process of community belief revision in light of new evidence which has been previously explicated (Anderson, 2008). Individual attributes include beliefs, motives, resources and credibility. Agent behaviors include assessing evidence and credibility, plus, adopting evidence and updating beliefs. The model includes opportunities for opinion leadership (regularly influencing the opinions of others) and serves as a starting point for answering questions about how and when opinion leaders emerge.

The programming of the NOL-ABMS is iterative and begins with programming the initialization or the "setup" of the model. This includes creating agents and setting the starting simulation parameters. The unit consists of an adjustable number of staff nurses (circles) and educators (squares). The agents all have their own variable beliefs, motives and credibility.

Figure 4.2 depicts the model interface. The slider bars are used to change the numerical values of variables. For example, the number of nurses can be set within a range of 50-200 individual agents. The assignment of other nurse-agent variables is computer generated and based on a random normal distribution with an adjustable mean and standard deviation. The "motive" variable is determined in this way, so that individuals are assigned random motives on a scale of 1-100, where motives < 50 are considered pragmatic (seeking to maximize best interest) and motives >= 50 are epistemic (seeking to maximize accuracy of beliefs). Adjusting the setting of the mean "motives" allows the user to observe agent behaviors on units that are more or less

pragmatic overall. Likewise, the initial prior-beliefs and unearned authority are randomly set on a scale of 0-100 to reflect probabilities. Adjustments to the standard deviation result in more or less variability among the agents. Earned authority, based on position is specified by rank, with the manager having the highest earned authority.

The program execution

Following completion of the basic set up procedure, the next step is programming the execution of the model (i.e. specifying what actually happens when the model runs). Actions such as agents obtaining new evidence, seeking opinions, and updating their beliefs occur. The first step in the NOLM is obtaining new evidence. The announcement of new evidence (with a random probability), by a random nurse, on a given unit, to the others on that unit, begins each sequence or "tick". Next, each nurse assesses the evidence and the credibility of its source. Assessment is achieved when the nurses compare their own beliefs and credibility to the new information. For programming purposes, evidence assessment was achieved by calculating the difference, in absolute value, of the agent's prior beliefs and the probability of the new evidence. The credibility assessment was similarly defined.

The new evidence is probable (to the nurse) if it is within a specified range of difference from the individual's own prior belief. The announcer is also credible relative to the assessor. In the case of "probable evidence," the nurses adopt the evidence and revise their beliefs. Programming of the belief revision rule took into account the prior beliefs of the nurse, the evidence and the credibility of the evidence announcer. The new belief was calculated as follows: .01 * (evidence-announcer-credibility * evidence + (100 - evidence-announcer-credibility) * prior-belief). The resulting strength of belief,

combined with the motives of the nurse, determines whether the individual will act on the belief by becoming visible to the other nurses (e.g. turn blue).

After each evidence assessment, if nurses are uncertain about either the evidence, or the credibility of the announcer, they may seek advice from other credible nurses with visible beliefs. If individuals are available to act as opinion resources, the uncertain nurses may adjust their assessments and either adopt the evidence or ignore it. Table 4.1 provides a summary of NOL-ABMS variable and procedure specifications.

Model verification

Model verification is the process of ensuring that the model is working correctly "as designed". The goal of verification is to reduce coding errors using various procedures for monitoring and "debugging" the computer code (Gilbert, 2008; North & Macal, 2007). Verification of the NOLM-ABMS occurred simultaneously with the iterative program development. For example, following the addition of each procedure, comparing computer generated computations to hand-checked calculations resulted in coding adjustments. The identification of problems by continuously monitoring parameters reported on the model interface for irregularities (i.e. negative numbers, or numbers outside the expected range) is another useful verification procedure. As the model development progressed, exporting simulation data into spreadsheets for analysis provided information that aided increasingly granular verification at the agent level. An example of "debugging" occurred with the discovery that the procedure for "updating beliefs" by replacing the "prior belief" with the "new revised belief" resulted in many nurses with new "prior beliefs" with a score of zero. Tracking the code execution revealed that simply changing the procedure, so that only nurses who actually revised

their beliefs replaced their “prior belief” for the next “tick”, or sequence solved the problem.

Exploratory analysis of simulated data

Once basic structural programming of the NOLM into the NOL-ABMS is complete, the performance of systematic model exploration procedures are used as a first step toward validation of the model. In order to gain insight about the conditions that affect the development of NOL (including the behaviors of the nurse-agents over time) two types of simulations were designed and executed for analysis. The first simulation procedure is “parameter sweeping”; it provides global data. The second simulation focused on individual nurse-agent attributes.

Parameter sweeping

Parameter sweeping is the process of systematically adjusting model variables in order to explore simulation results using multiple combinations of possible conditions (Gilbert, 2008; North & Macal, 2007). In order to explore potential differences, the design of the parameter sweep included values for the NOL-ABMS variables (unit size, number of educators, prior beliefs, motives, earned authority, evidence and credibility threshold) purposely selected to enable comparisons among units with substantial differences. Specified parameter selection for each of the above variables resulted in 288 possible combinations. Table 4.2 shows the details of the prescribed parameter values and variables included in the data collection. For each of the 288 combinations, sequential model execution occurred 50 times (e.g. 14,400 model executions total). The selection of 50 iterations was based on balancing the need for replication with the practicalities of computer power. The resulting data was saved to a spreadsheet for analysis. The

individual simulation results for each of the 288 combinations are combined in the form of means and/or counts for each variable of the 50-run simulation.

Results of parameter sweep

According to the NOLM, individuals must be visible in order to be available as a resource for others who are seeking another opinion about new evidence. Individuals become visible when they act on the strength of their beliefs. In addition, a person's motives influence visibility by changing the threshold for action; those with pragmatic motives are more likely to act at a lower threshold of belief.

In the NOL-ABMS program, nurses display visibility by changing color based on their beliefs and motives. Regression results, from the parameter sweep data, indicate that the ABM is performing consistent with the theory, with prior beliefs ($F = 123.265$, $p < .001$), motives ($F = 8.107$, $p < .001$) and evidence ($F = 106.019$, $p < .001$) all significantly contributing to the number of visible agents ($r^2 = .455$). Pragmatic motives and higher prior beliefs have a positive association, whereas epistemic motives and low prior beliefs are negatively associated with agent visibility.

The NOLM posits that the development of opinion leaders depends on the availability of nurses able to perform the role, as well as the presence of individuals who are opinion-seekers. Availability occurs when nurses viewed as credible have beliefs that are visible to their colleagues. General linear modeling of the global parameters on the mean number of agents with "in-links" (e.g. sought out for their opinions) reveals that most of the variables are significant predictors ($r^2 = .566$) of agents with "in-links". The number of educators and the motives were the exceptions.

The number of nurses on the units significantly affected the mean number of those agents with visibility. In addition, the mean numbers of nurse-agents available for opinion sharing was significantly different based on the size of the unit. Visibility was a significant predictor of availability ($F = 84.643$, $p < .001$, $r^2 = .228$), as was credibility ($F = 96.837$, $p < .001$, $r^2 = .253$). This was expected since the NOLM specifies that both visibility and credibility are required for nurse-agents to be available for acting as potential opinion leaders.

The environments that had nurses that tended to be more pragmatic were associated with a higher mean number of nurses with in-links. Units with low mean prior beliefs had fewer of these individuals. Motives and prior beliefs are both associated with visibility, a key condition required for being available as an opinion resource. Overall credibility was also a significant variable for predicting in-links. The credibility threshold for an individual, sought out for opinion, was associated with fewer numbers of nurses with in-links as it became higher. This result is not surprising since the threshold reduces the numbers of credible nurses available to act as potential resources for opinion advice. The unit size was also a factor, with larger units producing more nurses with in-links since there is a larger pool from which to draw.

In all of the 288 cases, at least a few of the agents needed another opinion to make a decision about the evidence. In 73 of the cases however, there were no opinion-givers available. Comparing the characteristics of the cases with a lack of available agents to the others, using descriptive statistics and ANOVA, shows that there are significant differences in prior beliefs ($F = 9.599$, $p = .002$), earned authority ($F = 107.912$, $p < .001$) required credibility ($F = 50.85$, $p < .001$), number of nurses ($F = 4.47$, $p = .013$) and

evidence ($F = 14.647$, $p < .001$). Motives and the number of educators were not significant. Low prior beliefs, low-earned authority and higher required credibility predicted a lack of nurses available for opinion sharing.

Individual agent results

The individual nurse-agent is the focus of the second simulation procedure. The simulation was devised to examine individual nurse-agents over time. In this case, the variables (i.e. unit size, number of educators, and means of initial prior beliefs, motives, earned authority, evidence and credibility threshold) were static for each of 20 model executions (e.g. data collection about the same individual agents at 20 "time points"). The parameter values for the variables, presented in Table 2, were selected to represent an "average" unit based on the range of possible values. The values for individual agent variables were collected and exported to a spreadsheet for analysis.

Similar to the results for the parameter sweep, prior beliefs, the evidence and the credibility of the evidence announcer were significant variables for predicting a nurse's decision to revise beliefs. Credibility and prior beliefs also predict the individual nurse whose opinion is sought (e.g. agents with in-links).

Individual agents with in-links were tracked over time to evaluate whether the same individuals had in-links at each time point. Four nurses had in-links over the course of the 20 ticks. None of these nurses were available to opinion seekers on every tick and one of them was available for in-links only once. The variation in availability is explained by changes in beliefs or credibility. Belief change, the result of revisions based on new evidence, can affect visibility, depending on the motives of the individual. Changes in credibility may be affected by visibility. This is because the credibility

calculation of nurses with visible beliefs weights more heavily toward the earned authority than the unearned authority, which is assigned based on the job title. Figure 4.3 shows an example of the relationships between motives, prior beliefs, credibility and in-links, over time, for one nurse-agent. Since nurse-agent #83 has a motives score of 88, the nurse will act on prior beliefs greater than 70. Since the credibility threshold for other nurses seeking an opinion is 65, nurse-agent #83 is both credible and visible, and therefore receives in-links from other nurses.

After a belief revision during run 11, nurse-agent #83's prior belief drops below the visibility threshold. This change in visibility affects the credibility since when the nurse-agents on the unit are unaware of nurse-agent #83's beliefs; they give more weight to the unearned credibility (which equals 50 because of the nurse position) than the unearned authority which is based on individual performance.

Opinion seekers may revise their beliefs based on the information obtained. In this 20 run series, the all of opinion seekers (47) were uncertain about the credibility of the evidence announcer. In addition, 11of these nurse-agents were also uncertain about the strength of the evidence. Like the nurse-agents with in-links, those agents who sought advice tended to display this characteristic over time, however 20 of the 47 sought advice only twice. In several instances, the revised assessment of the evidence based on the second opinion resulted in a decision to ignore the evidence.

Discussion

The construction of the NOL-ABMS presented here represents the basic structure of a theory of opinion leadership, described in terms of a nursing scenario. Iterative development and verification testing resulted in a dynamic model capable of producing

simulation results consistent with the proposed theory. Parameter sweep and individual results indicate that nurses revise their beliefs based on their previous opinions and their assessment of new evidence. Sometimes, the new evidence is of questionable credibility and is either ignored or further explored by seeking the opinions of credible colleagues.

The simulation results also show that nurse agents act on their strength of beliefs and, as a result, become an opinion resource for their uncertain colleagues, depending on their perceived credibility. Over time, a few individual agents consistently act as this type of resource and have the potential to become opinion leaders—those individuals who frequently influence the opinions of others when they are sought out for advice. Analysis indicates opinion leaders are more likely to emerge on units in which there are credible nurses with strong beliefs, available to act as resources for other nurse-agents who are uncertain about new evidence.

Counter to expectations, the number of educators did not contribute to the number of potential opinion leaders. Though not directly comparable, Milner, Estabrooks and Humphrey (2005) have suggested the clinical nurse educators are well positioned to be facilitators for increasing research utilization. A number of potential reasons for the lack of significance of nurse educators in the NOL-ABMS exist, including a lack of agent specificity and the possibility of not having attained a threshold number of educators.

Future simulations using “sensitivity analysis” may lead to different results. For example, instead of limiting tested values of number of educators to 3 and 7, the number is systematically increased to test whether or not there is a threshold number (or percent of the population) of educators that would affect the development of opinion leadership or belief change (Gilbert, 2008). Increasing the heterogeneity of the “educators” to

include various categories of nurses involved in staff development may also be useful, for example differentiating between preceptors, education coordinators and clinical nurse specialists.

The degree to which the nursing unit consists of both uncertain staff members and others willing and able to share their opinions has implications for predicting the usefulness of an opinion leader strategy for improving the adoption of evidence-based nursing practice. For example, on a unit composed primarily of novice nurses, there may be a lack of credible resource persons. On a unit of mostly expert nurses, with strong beliefs, the credibility threshold may be so high that it prevents any reliance on the opinion of colleagues when making decisions about revising beliefs based on new evidence.

Future development of the NOL-ABMS

The NOL-ABMS, in its present form is general, abstract and is potentially applicable to groups other than nurses. As a representation of the NOLM (Anderson, 2008), the ABM is a partial model that does not include some of the more detailed aspects of variables in the original model. According to Miller and Page (2007), the process of developing and interacting with a computational model often leads the theorist to discover new insights and avenues for further development of the model. Several priorities for model extension and increased specificity were identified based on the development, verification and validation results described here. These suggested revisions are described next.

Increasing the dimensionality of the nurse-agents and the characteristics of the evidence are priorities for enhancing the correspondence of the model with real world

situations and increasing its usefulness. Increased specificity of the agents and the evidence will contribute to further process refinements related to credibility and belief revision.

In terms of increasing agent heterogeneity, characteristics such as level of education, age, years of experience, and shifts worked are examples of factors that could provide diversity. Adding other types of agents, such as physicians or hospital administrators would add another level of complexity that has potential for differentiating how, or if, opinion leadership differs among professional groups. Expanding the social networks of the agents is also a priority. In this iteration of the NOL-ABM, it is assumed that all of the agents know each other and equally well. Variations based on length of acquaintance, professional group, job category and the addition of one, or more, different nursing units may improve the explanatory power of the model. In addition, these factors can affect credibility and access to evidence and could therefore contribute to strengthening the representation of these processes.

Because of the key role of subjective credibility assessment in the evaluation of evidence and the emergence of opinion leaders, refining the process of credibility assessment is a priority for model improvement and extension. For example, personal authority, based on characteristics such as friendship ties, or prestige is another potential component of credibility assessment (Kitcher, 1993). Other network effects, such as the strength of relationships, formation of cliques, and connections, or lack of connections, between groups may contribute to the ability of agents to assess each other's credibility or affect the accuracy of the assessment. By adding some complexity to the social

environment, an enhanced understanding of the conditions conducive to opinion leader emergence may be possible.

The process of credibility assessment is important not only for the identification of potential opinion leaders, but also for determining an agent's perceived need for another opinion which becomes apparent when the agent assesses the new evidence. Areas for improved NOL-ABMS development in this area include incorporating agent preferences for which particular agent's opinion they may seek and to what degree the new opinion influences the agent's assessment. Additionally, potential improvements to aspects of the new evidence and the evidence announcement procedure were identified. These include allowing individual agents to act as intermediaries for bringing new evidence to other groups or having agents consider the weight of the evidence when revising their beliefs.

Although normative models such as the NOL-ABMS can provide useful insight for understanding phenomenon such as NOL, an important advantage of using ABMS as a theory development tool is that it is possible for the model developer to include actual empirical data when programming variables. Instead of assigning random values to characteristics such as age or years of experience, real world data, if known, may define the agent attributes in the program. In addition to using "hybrid" models, containing both real and simulated values, for exploration and scenario predictions, the comparison of simulated and empirical data can lead to improved theoretical explanation and knowledge discovery. ABMS can potentially highlight the need for empirical data collection that would not be evident without the use of a theoretical model (Epstein, 1999).

Conclusions

ABM is a useful tool for theory development in nursing. Beginning the process of ABM development with a clear understanding of the essential attributes and process provides a framework and basic structure for model development. The NOL-ABM presented in this paper is a first step that provides these basic elements. The process of continued, iterative model extensions, such as those described above, enables the development of a model that provides just enough detail for theoretical explanation without introducing extraneous variables that add unnecessary complexity (Miller & Page, 2007). The next steps include combining extensions or revisions with ongoing verification and validation procedures, including empirical data collection. The overall aim is to contribute to the development of a workable, dynamic representation of opinion leadership in nursing.

Figure 4.1 The NOLM (Anderson, 2008)

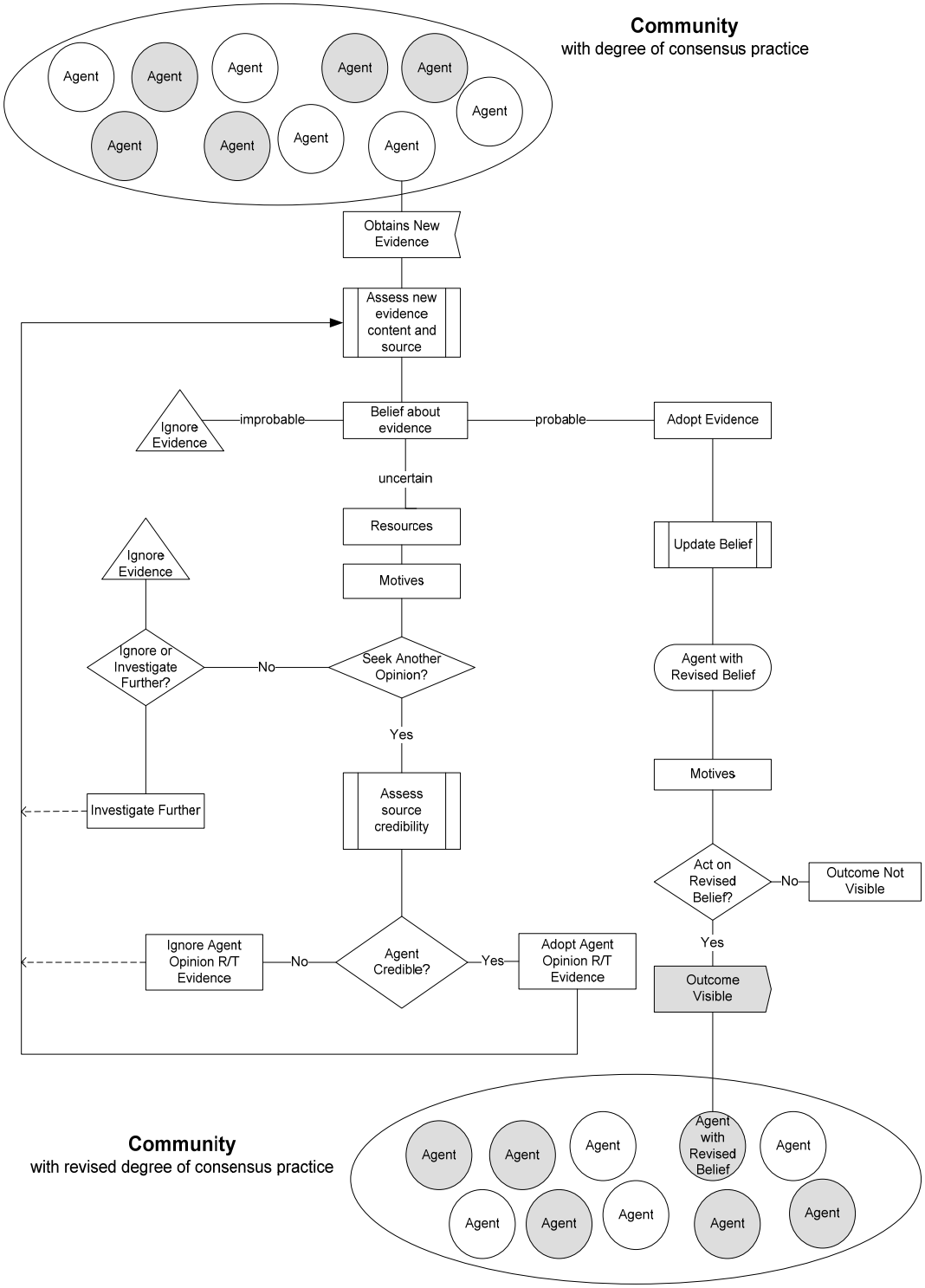

Figure 4.2 The NOL-ABMS program interface

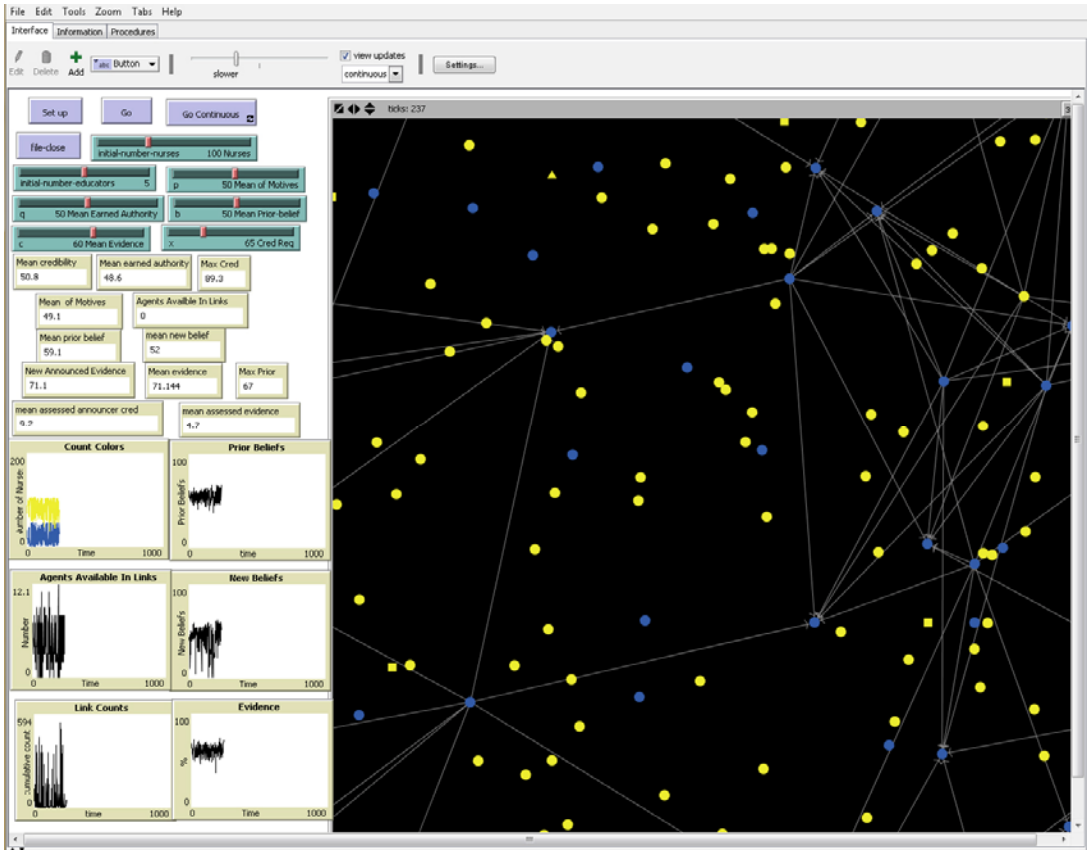

Figure 4.3 Availability of an agent to give advice over time

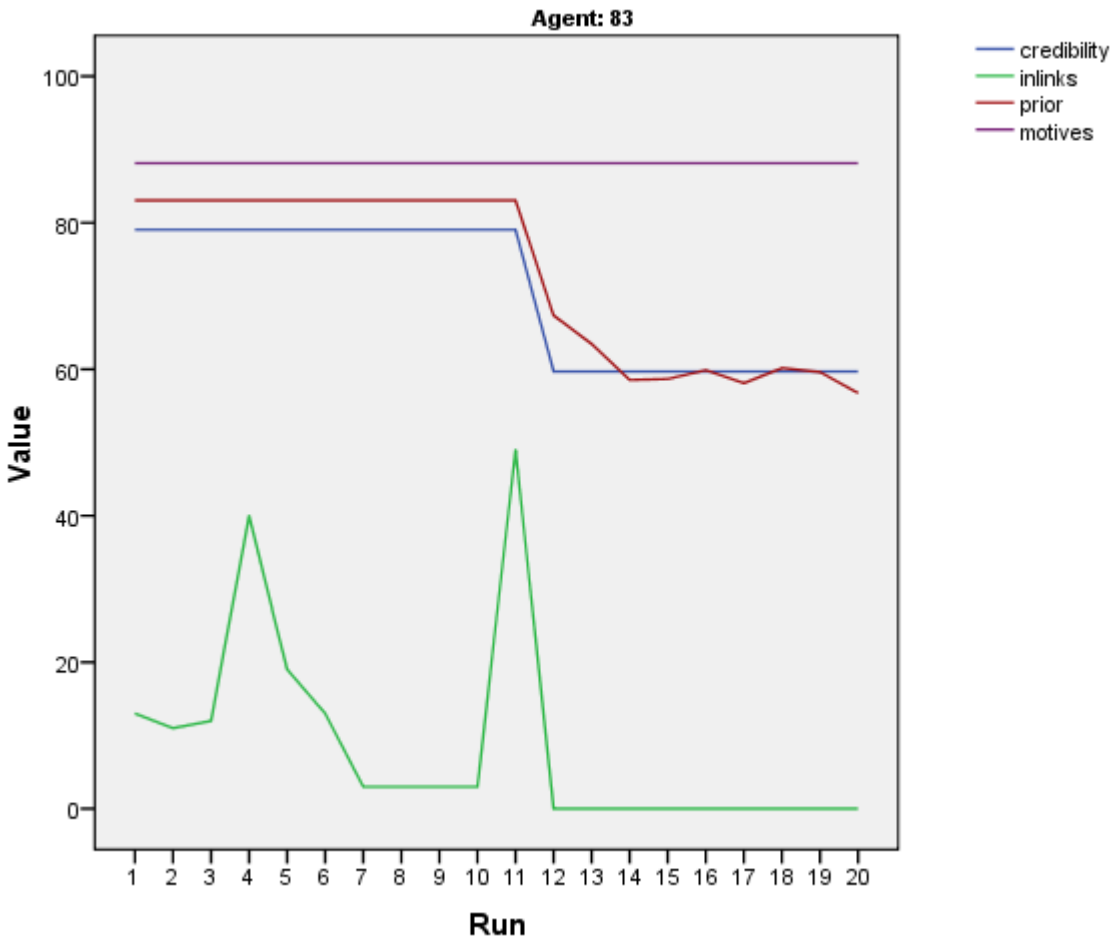

Table 4.1 NOL ABMS variables and procedures

Agent attributes and procedures	Specifications
Unearned authority (UA)	Defined by position: UA of nurses = 50, UA of educators = 80, UA of managers = 90
Earned authority	Random-normal distribution (1-100) with adjustable mean
Credibility	Weighted combination of earned and unearned authority. Weight based on visibility of agent.
Visibility	Strength of belief combined with a threshold based on motives. Pragmatic agents have a lower prior-belief threshold for visibility. Indicated by color blue
Prior-belief	Agent belief at beginning of process. Initial setting is random-normal distribution (1-100) with adjustable mean. Sequential values are determined by the belief revision process.
Evidence	Announcement of random value (1-100 with adjustable mean) by random agent with credibility *X*
Assessed evidence	Absolute value of the difference between an agent's prior belief and the evidence.
Assessed credibility	Absolute value of the difference between an agent's own credibility and credibility of the announcer
New belief	Result of adopting new evidence, replaces prior-belief for the next sequence.
Motives	Random-normal with adjustable mean. < 50 – pragmatic, >=50 – epistemic.
Availability	Visible agents with adjustable threshold of credibility available for giving opinion to other agents seeking advice
Need advice	Agents who are uncertain about the evidence or the credibility of the announcer.
Get advice	Agents who need advice create links with available opinion resources. Reassess evidence and announcer credibility based on the beliefs and credibility of the opinion resources
Revise beliefs	Agents change their beliefs based on their prior beliefs and a threshold assessment of the evidence.

Table 4.2 Parameters and data collection for simulation procedures

Parameter settings	Results reporting
Parameter sweep Number of nurses [50, 100, 200]* Number of educators [3, 7] Mean prior-belief [35, 65] Mean earned authority [35, 65] Mean motives [35, 65] Mean evidence [40, 70] Credibility threshold for giving advice [60, 70, 80] Number of iterations [50]	Count agents with: Color yellow Color blue Availability Need advice In-links Out-links Revised evidence assessment Revised credibility assessment New beliefs Mean of: Evidence announcer credibility New beliefs
Individual agent time series Number of nurses [100] Number of educators [5] Mean prior-belief [50] Mean earned authority [50] Mean motives [50] Mean evidence [60] Credibility threshold for giving advice [65] Number of iterations [20]	Prior belief Evidence Earned authority Credibility Assessed evidence Assessed credibility Motives Availability Need advice Number of in-links Number of out-links Revised assessed evidence Revised assessed credibility New belief

* Numbers indicate the values of the variables used in the simulation procedures.

References

Anderson, C. A. (2008). Nursing opinion leadership: A model derived from philosophic theories of rational belief. Unpublished manuscript

Epstein, J. M. (1999). Agent-based computational models and generative social science. *Complexity, 4*(5), 41-60.

Gilbert, N. (2008). *Agent-Based Models*. Thousand Oaks, CA: Sage Publications.

Kitcher, P. (1993). The organization of cognitive labor. In *The advancement of science: Science without legend, objectivity without illusions* (pp. 303-389). New York: Oxford University Press.

Miller, J. H., & Page, S. E. (2007). *Complex Adaptive Systems: An introduction to computational models of social life*. Princeton: Princeton University Press.

Milner, F. M., Estabrooks, C. A., & Humphrey, C. (2005). Clinical nurse educators as agents for change: increasing research utilization. *International Journal of Nursing Studies, 42*(8), 899-914.

North, M. J., & Macal, C. M. (2007). *Managing business complexity: Discovering strategic solutions with agent based modeling and simulation*. New York: Oxford University Press.

Wilensky, U. (1999). NetLogo. Evanston, Ill: Center for Connected Learning and Computer-Based Modeling, Northwestern University, http://ccl.northwestern.edu/netlogo/.

Chapter V

Summary, Conclusions and Avenues for Future Research

This dissertation introduced agent-based modeling (ABM) as a new methodological tool for theory development in nursing. In chapter two, a philosophic analysis of ABM, recurrent themes concerning the use of ABM in multidisciplinary research were identified. These themes (heterogeneity, dynamics, adaptation, emergence, and the metaphorical use of the term “bridge” to describe ABM) were examined from various philosophical positions in nursing. The ABMS themes were found to be compatible with multiple philosophic viewpoints within nursing. Further analysis, linking the recurrent themes with nursing metanarratives via exemplars from nursing systems research, revealed that ABM is a methodological tool that is congruent with nursing values.

Chapter three described the development of a nursing opinion leader model (NOLM) derived from two philosophical theories of belief formation. The resulting model is a normative, abstract, multi-level depiction of changing opinion. Dynamic repetition of the model predicts the emergence of opinion leadership (OL) by explaining how, under conditions of uncertainty, seeking the advice of others can affect belief revision. Although the model was described in nursing terms, empirical testing, using nurses as subjects, is required to verify how the model is specific to nursing, a limitation of the present study.

An advantage of the abstract model it is usefulness for depicting a basic framework on which to develop the complexities of OL. Basic assumptions include the influence of prior beliefs on opinion revision given new evidence; the influence of peer interaction on opinion revision; the influence of motives on action and the importance of contextual factors in a community on the need for and emergence of opinion leaders. Of particular significance is the notion of subjective credibility assessments among community members about the evidence and about each other.

In chapter four, the creation of an ABMS of the basic features of the NOLM was described. Executing the program and collecting simulated data enabled the first steps toward model verification and validation. Generally, this provisional model performed as expected, depicting opinion leadership as a dynamic process that develops under conditions of uncertainty when credible individuals are available as opinion resources. The NOL-ABMS provided useful insight for understanding OL. Although simulation is an advantage of using ABMS, the lack of empirical evidence in this study is a limitation. Plans for future development of the NOL-ABM were described in the chapter and further avenues for continued research are discussed in the next section.

Overall, this dissertation demonstrated the usefulness of ABMS as a methodological tool for theory development in nursing. The results also illuminate areas related to nursing philosophy, opinion leadership and agent-based modeling that could benefit from further research.

Neomodernism

According to Reed, her work on the development of neomodernism began because neither modernism nor postmodernism were congruent with her perspectives on

nursing practice and nursing science (Reed, personal communication, September 14, 2008). Further development of the tenets of neomodernism as put forth by Reed (1995, 2006) should be explored, and extended in order to better understand and evaluate it as a philosophic basis for nursing practice and research.

The literature concerning neomodernism is limited, however it is possible that issues related to terminology may contribute to the problem. A simultaneous concept analysis of neomodernism, along with "post-positivism" and "post-postmodernism" would help to clarify similarities and differences among these loosely defined schools of thought.

Further exploration of Reed's influences should be attempted in order to engage in a critique of the neomodern view. Examples identified by Reed include critics of postmodernism, as well as scholars of lifespan development and romanticism (Reed, 2008). Critical realism is a central tenet of neomodernism (Reed, 2006, 2008) and is of growing interest in nursing (Bergin, Wells, & Owen, 2008; Lipscomb, 2006, 2008; Wilson & McCormack, 2006). Replication of Beckstead and Beckstead's (2006) study using bibliometric co-citation analysis and multi-dimensional scaling to trace the origins and trajectory of nursing theory could prove to be a useful way of mapping neomodernism within the philosophic knowledge domain of nursing, and as it relates to other fields.

Development of the normative model of nursing opinion leadership

The normative model of opinion leadership developed in chapter three could benefit from further exploration of philosophic and other theoretical works. Specifically, additional research on how motives influence action would be helpful. Chapter three

focused on Bayesian epistemology. A useful next step would include examining pragmatic justifications for belief revision. Alternatives to probabilistic decision theory should also be explored, for example, Kahneman, Slovic and Tversky's (1982) work on the role of heuristics and biases in decision-making. Finally, understanding of subjective credibility assessment could also be enhanced. A starting point for development in this area is additional work by Kitcher (1993) that seeks to explain how prior practices contribute to the evaluation of credibility via arguments about propensities, observation, inductive generalization and rival possibilities (Kitcher, 1993).

Further development of NOL-ABMS

In chapter four, a number of priorities for further development of the NOL-ABM were discussed. Priorities for model extensions were increased heterogeneity of agents, increased complexity of the social environment and greater specificity related to credibility assessment. Understanding and assessing the validity of ABMS is a key requirement for developing credible nursing models. Further validation of the NOL-ABMS can proceed in several directions. Initially, further specification of the model, along with the use of content experts to evaluate face validity will improve the simulations. Second, comparing results of the simulation with results from published empirical opinion leader research, both qualitative and quantitative is an important next step. Developing model ensembles, hybrid models (with empirical and simulated data) and comparison of the NOL-ABMS with similar models will be useful for planning research designed to gather empirical data from practicing nurses. Nursing data is essential for a more complete understanding of how opinion leadership works in nursing.

This dissertation has demonstrated the potential for using ABMS for the development of nursing knowledge. Although this dissertation has focused on the use of ABMS for theory development, it is also important to consider other implications for nursing research, as well as nursing practice and education. The introduction of new methodological tools such as ABMS raises important questions and implications. Further research is required to clarify and answer these potential issues.

From a practical standpoint, ABMS permits the use of simulated data to examine theoretical relationships prior to the collection of actual data. The implications for research when used in this way, is the possibility of using ABMS to function as a type of pilot study, where potential problems can be identified and averted. As more details are included in an ABM, simulations produced using the model may become more life-like. This raises the questions about when, or if, it is appropriate to put forth recommendations based on simulated data. As is true with other means of theory development and testing, an important criterion is the extent to which the model and simulation results represent the real world—i.e., the validity.

As the use of ABMS has grown, discussions concerning methods for testing the validity of ABMS have appeared in the literature. Examples of methods used to test for validity of ABMS results include techniques familiar to qualitative researchers, for example checking results with individual sources for model inputs, debriefing techniques and the use of subject matter experts to contribute to the face validity of a model (North & Macal, 2007).

Moss and Edmonds (2005) describe the use of both qualitative and statistical comparisons of ABMS with observed data. Continued efforts to improve model

comparison techniques as a means of contributing to validity and theory testing include "docking," a means of aligning models to make them comparable (Kuznar, 2006). Multi-scenario simulation strategies to compare alternatives, for example policy options (Moss, 2002) or decision-making strategies (Kuznar, 2007) have also been used to develop valid models.

This dissertation presented an exemplar case of using ABMS to develop and test a normative model of a phenomenon of interest to nursing systems researchers. As shown in the philosophic analysis, the range of topics studied using ABMS is vast and it is likely that the method will be useful to examine a range of nursing and interdisciplinary issues. Because of its flexibility, ABMS has been used by researchers to develop theories about processes and outcomes using a variety of approaches, some highly abstract, others minutely specified, using quantitative empirical indicators, and still others a blend of both.

From the standpoint of nursing practice, there are a number of possibilities for the use of ABMS by nursing managers and those nurses engaged in public policy. Examples include developing simulations of operational issues such as staffing or patient flow. Modeling could also be used to examine data for potential patterns related to patient safety, or to "pilot test" proposed changes. Multi-model comparisons of policy options or intervention strategies may also be useful.

In terms of education, ABMS has been used with all age groups to teach complex concepts. Within nursing, the use of simulation for learning is not new, but is becoming more prevalent and sophisticated, along with the development of advanced devices used for practicing patient care. ABMS is a cost-effective way to provide an interactive

experience for students at both the undergraduate and graduate level. Ongoing research about the use of ABMS in the classroom as well as the development of new tool kits and curricular enhancements are the focus of interested groups such as the *Center for Connected Learning and Computer-based Modeling* at Northwestern University (http://ccl.northwestern.edu/).

References

Beckstead, J. W., & Beckstead, L. G. (2006). A multidimensional analysis of the epistemic origins of nursing theories, models, and frameworks. *International Journal of Nursing Studies, 43*(1), 113-122.

Bergin, M., Wells, J. S., & Owen, S. (2008). Critical realism: a philosophical framework for the study of gender and mental health. *Nursing Philosophy, 9*(3), 169-179.

Kahneman, D., Slovic, P., & Tversky, A. (Eds.). (1982). *Judgment under uncertainty: Heuristics and biases*. Cambridge, UK: Cambridge University Press.

Kitcher, P. (1993). *The Advancement of Science: Science without legend, objectivity without illusions*. New York: Oxford University Press.

Kuznar, L. A. (2006). High-fidelity computational social science in anthropology - Prospects for developing a comparative framework. *Social Science Computer Review, 24*(1), 15-29.

Kuznar, L. A. (2007). Ensemble computing in agent-based modeling for transcending paradigmatic boundaries in decision theory--understanding tribal politics. In M. J. North, C. M. Macal & D. L. Sallach (Eds.), *Proceedings of the Agent 2007 Conference on Complex Interaction and Social Emergence, Co-sponsored by Argonne National Laboratory and Northwestern University, November 15-17* (pp. 433-441). Evanston, Illinois.

Lipscomb, M. (2006). Book Review: Critical realism, post-positivism and the possibility of knowledge by Ruth Groff. *Nursing Philosophy, 7*, 104-105.

Lipscomb, M. (2008). Mixed method nursing studies: a critical realist critique. *Nursing Philosophy, 9*(1), 32-45.

Moss, S. (2002). Policy Analysis from First Principles. *Proceedings of the National Academy of Sciences of the United States of America, 99*(10), 7267-7274.

Moss, S., & Edmonds, B. (2005). Sociology and simulation: Statistical and qualitative cross-validation. *American Journal of Sociology, 110*(4), 1095-1131.

North, M. J., & Macal, C. M. (2007). *Managing business complexity: Discovering strategic solutions with agent based modeling and simulation*. New York: Oxford University Press.

Reed, P. G. (1995). A treatise on nursing knowledge development for the 21st century: beyond postmodernism. *ANS Advances in Nursing Science, 17*(3), 70-84.

Reed, P. G. (2006). Commentary on neomodernism and evidence-based nursing: implications for the production of nursing knowledge. *Nursing Outlook, 54*(1), 36-38.

Reed, P. G. (2008). Pam's notes on neomodernism. University of Arizona. Unpublished manuscript.

Wilson, V., & McCormack, B. (2006). Critical realism as emancipatory action: the case for realistic evaluation in practice development. *Nursing Philosophy, 7*(1), 45-57.