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A Design Artifact for Distributed Cognition: "Natural Science" Pilot Leads to an Expanded Design Science Program

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A Design Artifact for Distributed Cognition:
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ABSTRACT

As part of an on-going design science project, we are developing "Theory Garden," a tool that enables individuals to easily generate visual causal models, thus making their perspectives explicit. Theory Garden aids in the drawing of personal theories of a situation as users indicate their assumptions with qualitative statements and simulate the resulting models. The intuitive interface is intended to minimize the barrier to use, and thus be accessible to a wide audience. The simulation engine enables users to better understand theoretical implications of their theories, and to engage in scenario-based simulation. This paper represents the first step in our effort to scientifically validate our use expectations for the software. In this step we identify a range of use patterns of untrained users. We address strategies for dealing with the unexpected variation that we found in personal modeling strategies, as well as a next step in our study.

Keywords

Design science, Theory Garden, perspective making and taking, qualitative modeling, systems thinking.

INTRODUCTION

In a design science study conducted more than a decade ago, Boland and associates (1994) articulated a set of principles for designing technological artifacts to support distributed cognition. The principles they described were then elaborated and verified through a number of subsequent studies (Boland & Tenakasi 1995; Ackerman & McDonald 1996; Majchrzak et al 2000; Majchrzak et al 2005). This subsequent literature focuses almost exclusively on the communicative aspects of distributed cognition, specifically highlighting the importance of "sweeping in" context for successful dialog. Such dialog, however, is only one aspect of distributed cognition as Boland et al (1994) initially identified. They argued that reflection and action are equally important activities associated with distributed cognition, and these areas have yet to be addressed in design science research.

"Distributed cognition" is a socio-cognitive theoretical lens that highlights the role of artifacts as constitutive factors in cognition. Because of their capabilities for making representations and performing computations, artifacts mediate and enhance individual reflection as well as interpersonal communication (Boland et al 1994; Hutchins 1995, 2000; Hollan et al 2000). To characterize specific ways in which artifacts can extend human cognition, Boland et al (1994) draw upon the traditions of philosophical hermeneutics (Gadamer 1976) and inquiring systems (Churchman 1971).

Our present design science research project is concerned with extending Boland et al's (1994) framework in the direction of individual reflection and action associated with distributed cognition. This research is based on a recent incarnation of the Spider software system (Boland et al 1994, Boland & Tenkasi 1995), which is named "Theory Garden."

In this essay we look to (1) briefly introduce the theoretical roots of Theory Garden software, as well as the software itself; (2) articulate our research agenda and describe a pilot study and the implications of our findings for further design, and (3) discuss the implications of this modest pilot project for design science research in general.

Of these three broad areas of discussion, perhaps the most important is the insight that our pilot project offers on the value of design science research in general. In this study we focus on an artifact that has been in existence for 15 years and has been used repeatedly by firms, in consulting engagements, and in classrooms. This pilot study was originally intended to be the first step of a research program in the "natural science" tradition (March & Smith 1995). We were intending to measure the limits of a human's ability to predict the implications of their theories, by simulating their theories and comparing their predictions against the simulations. We were expecting their abilities to be fairly limited, and we were looking mainly to quantify this limitation. What we discovered, even before we simulated the first model, was that we did not understand the use patterns of the software artifact properly. People simply did not naturally conceptualize models as we expected, and we found that many models were either too simple or too complex. Rather than to continue down a path of exploring human limitations, because of this pilot study we have returned to our goal of enhancing human action. In this we are again pursuing a design science agenda, while, for the moment, refraining from the natural science course upon which we began. This design science agenda frees us to be normative, positive, and opens up a rich new line of inquiry.

THEORETICAL FOUNDATION

Distributed cognition theorists point out that the traditional expediency of bounding cognition within an individual is an arbitrary delimitation. Instead, a cognitive process should be bounded in accordance to function, since cognitive activity takes place across people and artifacts as well (Hutchins 1995, 2000; Hollan et al 2000): "A cognitive process is delimited by the functional relationships among the elements that participate in it, rather than by the spatial co-location of the elements" (Hollan et al 2000, p.2).

Technological artifacts are essential for distributed cognition, as they support the dialog and interpretation required for communication and learning (Boland et al 1994). From a perspective of distributed cognition theory, artifacts can be said to have three facets: (1) communication support, or (2) computation; and (3) capturing knowledge across time (Hutchins 1885, 2000). Boland et al (1994) identified six principles for designing technologies to support distributed cognitive activity: *ownership, easy travel, multiplicity, indeterminacy, emergence,* and *mixed forms.*

In this design science research project, we are focusing exclusively on the relationship between the individual and the artifact. Therefore, "ownership" for example, is not an issue. Thus, from a standpoint of an individual engaged in cognitive activity with an artifact (but not other individuals), we reconceptualize the three distributedly cognitive purposes of the artifact to be: representation (communication with one's self or with others), computation (information processing), or embedded knowledge (of others within the artifact). Following, we will briefly address each of these.

- *Representation* of cognitive activity with the aid of a physical artifact enables individuals to more finely articulate concepts and to use these articulations for improvement of those concepts, or to aid the individual's computational ability. Representations can also be used to formulate and document multiple alternative concepts from which an individual can choose as part of a decision process (Simon 1996). An example of distributed cognition across a representational artifact is the use of a pencil and paper to solve a mathematical problem.

- Many artifacts, particularly technological artifacts, can also shoulder the *computational* burden of cognition. Rather than merely amplifying an individuals thought processes, computational artifacts can amplify the cognitive capabilities of the individual (Hutchins 2000). An example of distributed cognition across a computational artifact would be the use of a calculator to solve a mathematical problem.

- Finally, artifacts may *embed the knowledge* of others who have previously completed the cognitive activity. The findings of previous cognitive activity throughout history are captured by the texts and tools around us, which black-box that knowledge so that individuals can use the resulting knowledge without necessarily understanding – let alone completing – the associated cognitive activity (Hutchins 1995). An example of distributed cognition via knowledge embedded in an artifact would be turning to the back of a text book to find the solution to a mathematical problem.

These three ways describe *what* an artifact can do to amplify an individual's cognition, and next we will explain *why* we are designing such an artifact in the first place. Prior research on causal modeling explored their role in making a perspective explicit, and in communicating perspectives across knowledge domains (Boland & Tenkasi 1995). Because coordination and collaboration of heterogeneous knowledge sources is critical to organizational innovation, our goal was to create a tool to facilitate that activity.

By re-focusing on the distributed cognition of an individual's interaction with an artifact, our goal remains linked to nurturing innovation. But, instead of an organizational level of analysis, we take an individual level view, and explore the innovative thinking they display when we "complicate" the managers' understandings of phenomena (Boland et al 1994).

Because of the limited energy they spent on reflection, managers tend to have an "impoverished" view of the world (Weick 1990). The over-simplified belief systems of managers have been linked to organizational decline and failure (Starbuck 1983). A fundamental way we wish to complicate peoples thinking is by bringing contextual elements into the purview of their analyses, by adding contextual elements to the representations they encounter. Hermeneutics offers a lens through which managers can appreciate contextually-enriched understanding. With its roots in the study of ancient texts, hermeneutic analysis was borne of the need to continuously compare data at hand to its historical context to arrive at increasing levels of understanding (the "hermeneutic circle"). The hermeneutic tradition has been adopted in order to gain phenomenological insight into the social world (Gadamer 1976) and involves the "tacking back and forth between theory and details, comprehension and particulars… setting layer upon layer of reciprocally validating relation between the overall grasp and the immediate instance" in order to enrich understanding (Boland et al 1994, p.461). Boland et al (1994) indicate that the inquiring systems approach offers a mechanism by which managers can judge the validity claims and limits to phenomenological interpretations borne of hermeneutic inquiry.

By viewing the world as a nested web of interconnected, hierarchical systems, managers must be selective about the salient system components they wish to address. System theorists often prescribe "models" as "a way in which thought processes can be amplified" (Churchman 1968, p.61). An important aspect of system modeling is to understand that every model reflects the manager's explicit and implicit assumptions, and that these assumptions can always be questioned on some terms (Churchman 1971). Hence, models can aid in a manager's thinking, but manager must be on guard against complacency. There must never be a "final" model, since new elements can always be "swept in" to a systems model, and alternative, defensible system models inevitably exist (Churchman 1971).

Therefore, we continue to develop the technical artifact of "Theory Garden" to accommodate distributed cognition, by an emphasizing context-rich interpretation and intuitive, flexible modeling. In this paper, we look to test the process of causal modeling from a perspective of an individual's, distributed cognition.

THEORY GARDEN SOFTWARE

Based on research in social cognition, we have developed Theory Garden[1] software - an artifact designed specifically to facilitate deeper levels of cross-community organizational communication (Boland & Tenkasi 1995) and distributed cognition (Boland et al. 1994). The fundamental strategy for improving such communication and cognition is based on the importance of contextualizing perspectives, an assumption which has been verified in the empirical literature (Majchrzak et al 2005; see also Majchrzak et al 2000; Malhotra et al 2001; Ackerman & McDonald 1996).

Although Theory Garden has expanded into a family of products, the core set of functions are intended to capture qualitative theory models through graphical representations of "relationships" between "elements." In visually capturing these models, Theory Garden software is intended to help individuals develop, articulate, and share understandings about particular phenomena (Boland et al 1994). This implementation of a visual thinking tool is intended to aid a user in surfacing and working through the assumptions that are brought to situations (often not explicitly) and guide that individual's understanding of situations. Figure 1 illustrates a model created in Theory Garden by one of the authors working with a doctor as they addressed that doctor's concerns with increasing pressure to cut costs and the impact this may have on various aspects of patient care.

As these models are intended to aid individuals in surfacing their assumptions, the user interface cannot be a barrier to usability. In order to enable access to a wide audience, the data input is strictly qualitative and largely visual.

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[1] Formerly named Spider (Boland et al 1994).

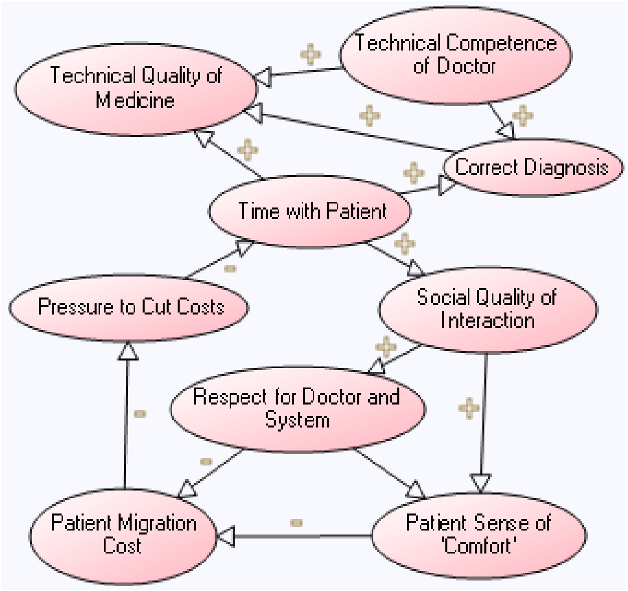

Figure 1: A Doctor's Model of Patient Care

Although the software has never been available commercially, researchers have applied the tools to a wide set of problems in both academic and industrial environments. Recently, the code has been redesigned and rewritten with a modern architecture (in C# .NET). A wide variety of intuitive human interface features have been added as well as animation functionality and advanced model interrogation capabilities. Also, the graphical representation can be simulated in an advanced qualitative system theoretic post processor, the TG-Engine (patent pending). This simulation engine relies on a hybrid set of techniques including statistics, mathematics, genetic algorithms and neural network logic to mathematically iterate through cycles of a given model, based on the qualitative relationships established in the user's model. This becomes an NP-complete problem with only a few elements, and the TG-Engine can simulate dozens of cycles through the model in seconds. It is not the purpose of this work to explicate on TG Engine – for more information, see Goraya (2001). Figure 2 provides a possible scenario resulting from the doctor's causal model described above.

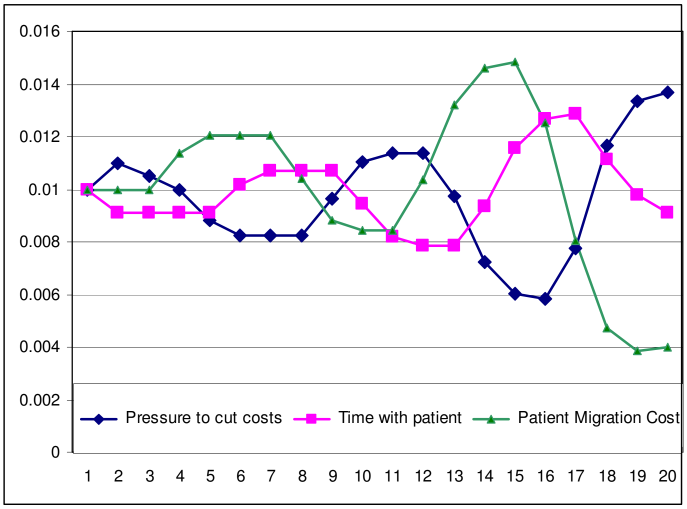

Figure 1: Sample Simulation of Doctor's Model

Armed with these easily accessible yet powerful "Theory Garden" tools, we have recently begun a new program of design science research – to test the ways in which such an artifact can be used to both construct and analyze individual understandings of a situation of interest. Our original course of inquiry focused on the way that simulations can bolster human cognition, but those initial findings led us in another direction. The patterns of system usage in our pilot test did not turn out as expected. Our new course indicates that before we tackle issues associated with simulations, we first stop to assess the patterns by which people interact with these artifacts.

RESEARCH DESIGN

The goal of this phase of the research was to compare an individual's ability to understand the implications of a causal model with the results from a simulation of that causal model. Thus we planned to effectively test the ability of individuals to accurately draw predictive conclusions from their own assumptions. To capture these assumptions we planned to conduct a series of studies using Theory Garden's mapping software. A series of data collection exercises were planned. A pilot exercise was intended to test our measurement instrument and protocol. After possible revision to the instrument and protocol, we planned to engage in pre-test activity, and then include a much wider range of participants in the main study itself, which would focus on simulation of an individuals' theory model. To date, we have completed a portion of the pilot exercise and user interaction with the system has not proceeded as expected, and it is premature to focus on the simulation. Instead, we discovered that we need to better understand design principles associated with the topology of user models.

The pilot exercise involved 43 total participants: 34 executives and managers; and 9 academics. The managerial participants included executives and managers from a range of sectors within the business community. The academic professionals included faculty and doctoral students. The data collection effort took the form of interviews, using pre-defined Theory Garden elements to mediate the interaction and capture the results. The subject was presented with a series of models, and it was up to the subject to determine the directionality, nature, and strength of the perceived relationships between entities in the models. The subject was also asked to predict certain outcomes based on their assumptions, with the intention of eventually comparing their predictions to the results of the simulations. Managerial practitioners were asked to address hypothetical models of employee motivation (that of the protocol), whereas the academic professionals focused on hypothetical models of student motivation. The intention was to provide the subjects with a topic that is very familiar – one about which they are likely have many explicit and implicit assumptions. We standardized the elements and labels to isolate and confidently compare the responses.

Protocol

1. A figure with multiple elements was presented to the subject, and the subject was asked if any elements had a relationship to each other. If so, the following four questions were be asked, and the subject answered from the options provided:
    a. What is the direction of the relationship? (to / from / bidirectional)
    b. What is the nature of this relationship?
        i. Positive / negative
        ii. Linear / exponentially nonlinear (hyperbolic) / normal (parabolic) / reverse parabolic
    c. What is the magnitude of this relationship? (strong / normal / weak)

2. After the subject has had a chance to review and change the relationships to their liking, he or she was asked to predict the movement of selected variables after one variable was increased (see figures below), in the immediate future and the longer-term trend.

    Figure A

    If salary increases by 25%, what will be the impact on stress, according to your model?

Figure B

If workload is increased 25%, what will be the effect on employee motivation over time?

If salary increases by 25%, what will be the impact on stress, according to your model?

Figure C

If the family factor increases, what will be the impact on employee motivation?

- on salary?

If salary increases by 25%, what will be the impact on stress, according to your model?

RESULTS

After conducting the pilot study with our 43 participants, we found that many of the subjects made causal models that were highly simplistic and therefore had trivial implications. This was especially true with the three-element models. In the case of such simple models, mathematical simulation was entirely unnecessary. On the other hand, we found that a number of participants created overly-complicated, unintelligible models as often as they described more parsimonious "systems" models among the 8-element models (which were both fairly rare).

We coded each model in one of the four following categories. Table 1 &2 summarize our results, and examples from the data follow.

- ***Too simple*** – Models were coded as "too simple" if there were no feedback loops or cycles in the model. For 5 and 8-element models, if exclusive sinks and sources (those with only either input or output arrows) outnumbered elements with both input and output, they were also marked as "too simple," as the result is a systems causal model of only two or three elements.

  Following are two examples of "too simple" 3-element models from the data. It is apparent that the subjects had a particular element in mind as the objective, and the other two were treated as drivers of that element.

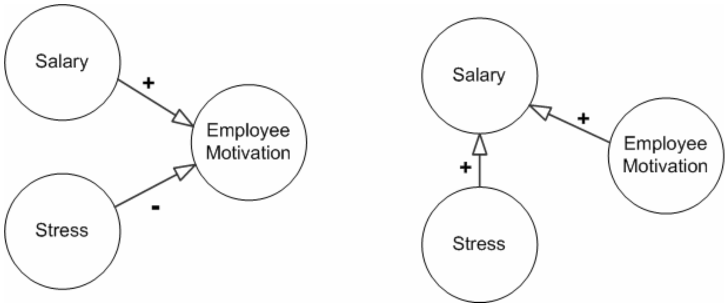

Figure 3 – "Too simple" 3-element models

Following is an example of a “too simple” 5-element model from our data. It is almost a caricature of how a manager might view employee motivation where none of the elements interact, and there is no feedback – employee motivation does not affect any of the other elements. [Note: this is the same subject as the first “too simple” 3-element model.]

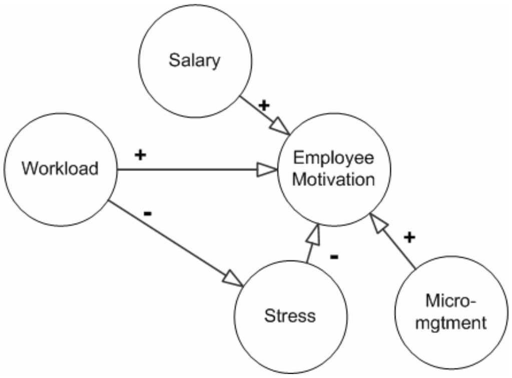

Figure 4 – “Too simple” 5-element model

Following is an 8-element “too simple” model. Note that all elements are either sinks or sources, and, as this again was the same individual from Figure 4, it appeared to be a pattern across the data that people carried their relationships from the first model through to the third. This pattern appears to have resulted in some of the complexity we observed in some models.

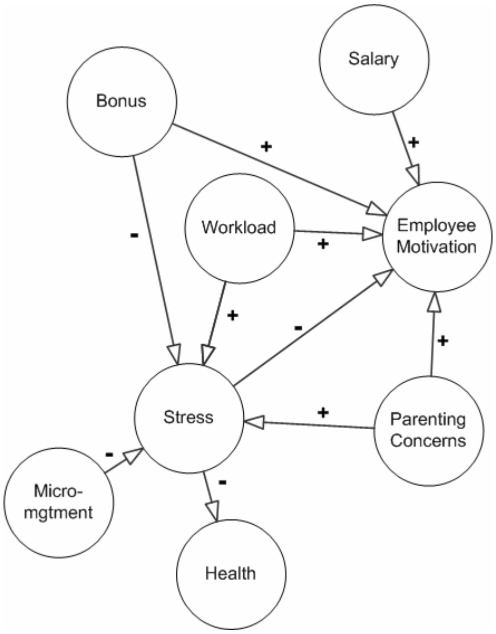

Figure 5 – “Too simple” 8-element model

- ***Too complex*** – Models became too complex to manage in the 5-element model if there were four bi-directional relationships, or if two elements had four relationships. For 8-element models, if there were five bi-directional relationships or two elements had six relationships, they were deemed too complex. Many 3-element models had bidirectional relationships among all elements, and we determined that this was not too complex.

Following is an example of an 8-element "too complex" model. Note that *employee motivation* has direct relationships with every other element, and the *stress* element has 6 out of 8 relationships, indicating an rather severe lack of parsimony.

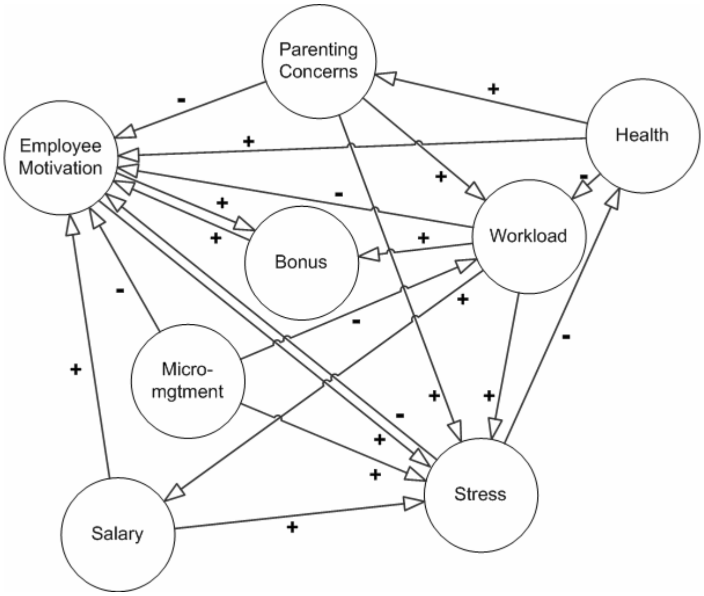

Figure 6 – "Too complex" 8-element model

- **Virtuous-Vicious** – This type of model exhibited no dampening relationships to off-set positive (or negative) feedback loops. That is, if any single element were perturbed, it would set off a never-ending self-feeding cycle in either a positive (virtuous) or negative (vicious) direction.

  Following are two examples of 3-element models. The first one illustrates a "vicious-virtuous" model, as the perturbation of either *salary* or *employee motivation* would set of a virtuous cycle, and the perturbation of *stress* would set off a vicious cycle. The next model (created by another subject) is an example of a "system model" as the virtuous-vicious cycle is dampened, or limited, by the positive effect of *salary* on *stress*.

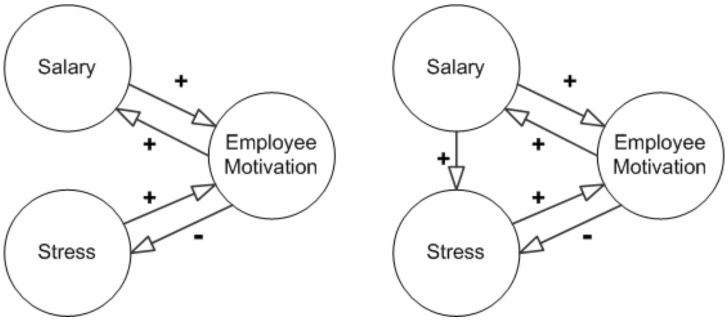

Figure 7 – A "virtuous-vicious" model(left) and a similar "system model"(right)

- **System** – System models are those that involved positive and negative feedback loops and cycles, as well as dampening cycles. As a model is intended to offer a simplification of reality according to the systems approach, we anticipated that systems models would be parsimonious. However, if there were more exclusive sinks and sources than there were elements with both input and output, then the model was not a system model.

Here is an example of a 5-element system model, while the *micromanagement* element is an exclusive source; all others are both sources and sinks. Also, the connections of the other elements are parsimonious. [Note: This is the same subject that did the system model in Figure 4.].

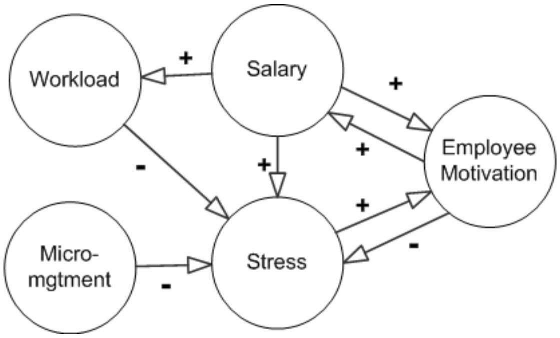

Figure 8 – A 5-element "system model"

Following is an example of an 8-element system model from another participant. There are three exclusive sinks and sources, while the rest have both input and output. There are positive feeback loops and dampening cycles, and the model appears parsimonious. It is one of only three 8-element system models in our data from 43 participants.

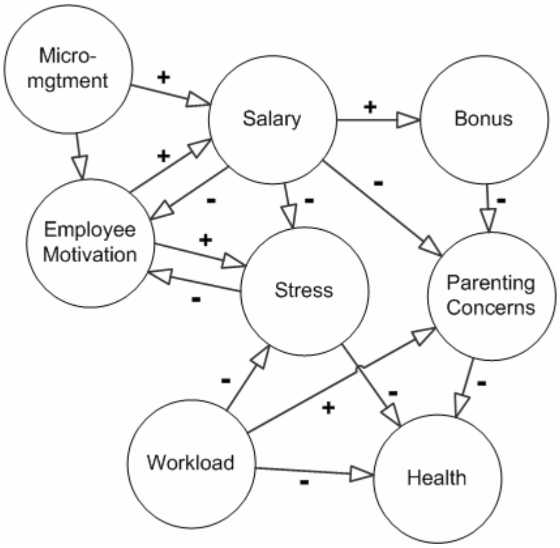

Figure 9 – An 8-element "system model"

Result summaries: Below Table 1 and 2 summarize our results. From these results we make a number of observations. First, it appears that Weick's (1990) assertion, that managers have impoverished world-views, seems to be supported by our data (Table 1). What is especially surprising is that models appear to become simpler as complexity increases. Also, while we do not have enough data to make any comparisons confidently, it does appear that academics tend to overly-complicate as often as they under-complicate, which is not the same case with the managers.

Table 1: Manager Results

	Model		
	3-element	**5-element**	**8-element**
too simple	16	24	26
too complex		1	4
virtuous-vicious	5		1
system	13	9	3

Table 2: Academic Results

	Model		
	3-element	**5-element**	**8-element**
too simple		2	4
too complex		1	3
virtuous-vicious	2	1	1
system	6	4	

DISCUSSION

This pilot study, intended to explore the ability of an individual to understand the behavior of their own theory model as the number of elements and causal relationships in their model increased, revealed another, unanticipated facet of constructing theory models. The notion that people are poor intuitive statisticians and had bounded rationality was behind that initial formulation of the work. But an awareness of and experience with design science enabled us to interpret the initial subject behaviors as revealing the need for a design science study. It revealed that subjects were consistently oversimplifying the theory models they constructed, and surfaced the need for a normative study of how the software system should be designed in order to help users to be more likely to create more appropriate, “better” theory models, which were neither too simple nor too complex.

Our pilot has opened a design problem to us in which the individual should be assisted in not undercomplicating or overcomplicating a theory model. Stimulating their ability to see relationships among variables is an important required design feature, but so is the ability to help them prune a model. It suggests that the user should be supported in constructing and recognizing well-formed theory models. There is not an obvious solution to this design problem, but it is one worthy of our future efforts in the cause mapping domain. More worthy than the attempt to measure a human limitation, what has been exposed is that our design science efforts have not gone far enough.

The experience we report here also highlights the importance of prototypes in design. Even though we did not intend it as a prototype, the users were put through a sequence of activities that revealed design requirements. The prototype did not mimic the intended use, which has an individual drawing a theory model by thinking of the elements in their theory, locating them on the screen and then linking them by causal relations. The simple shift in which users were given the elements and asked to relate them causally brought out a unique understanding of their capacity to create theory models.

The prototype experience showed that people have relatively few strategies for shaping a theory model. One is a “radiant” image, with elements leading into a central “variable”, or leading out from it to subsidiary effects. Another is a “system” thinking approach with loops of inhibiting or exciting feedback. A third is an “everything is related to everything approach” with almost all elements linked to almost all others. Neither the “radiant” nor the “everything related” strategy provides a helpful model of a theory for about how a socio-economic situation will unfold. The radiant image shows a one directional change that may follow a single perturbation. The “everything related” strategy shows a chaotic, unpredictable pattern that cannot be interpreted meaningfully.

The design problem that follows from this prototype experience is quite different from the design problem that we posed when designing the Theory Garden (then “Spider”) software in the first place (Boland et al 1994). At that time, we were working with the assumption that people had personal theories (or schema, or frames) and the design problem was to make it intuitively easy to draw that understanding so that others could relate to it. As the project progressed, we saw that people discovered a theory as they drew small fragments and connected them. This changed the design problem to be: help the individual construct a theory from the “unassembled” set of elements and relations that were in their mind but unformed. Now, with this unintended prototype experience, the design problem changes once again, to be something like: enable a person to move from radiant images of relations among entities to systemic ones, without allowing the number of loops to grow too large and overpower the logic of the system.

Thus the next steps for the design of Theory Garden will involve basing new functionality on specific theoretical foundations (Hevner et al 2004). As the intention is to encourage simple models to become more complicated, to promote parsimony for highly complex models, and to suggest dampening for models with self-feeding cycles, a number of options are available to us. A preliminary list of options we have discussed includes the following:

- complex pattern-recognition algorithms that can intelligently analyze models and make suggestions for improvement
- non-directive interview somehow embedded in the system that will prompt user self-reflection
- question the assumptions of the model through alternative arguments (in the spirit of Churchman’s 1968 “deadly enemy” program), perhaps by using a text scan and search for synonyms and antonyms
- functionality to collapse elements into a higher-level element and thus simplify (in the Singerian tradition, Churchman 1971)
- functionality to suggest context, and thus complicate (Singer again, Churchman 1971; Gadamer 1976)

The move towards reframing our study from one measuring “human limitations” one, to one aimed at a “betterment of human performance.” We have not developed that study yet, but the difference between the initial natural science (March & Smith 1995; “behavioral science paradigm” in Hevner et al 2004) approach we had taken, and the design science approach that the pilot revealed for us is a wonderful example of how approaching our work by mimicking natural science is profoundly different from approaching it as design science. Following a natural science approach, we had hoped to make precise measures of the limits of humans to anticipate the logical consequences of their own systems theoretic models. Now, with our shift to a design science approach, we are attempting to normatively intervene in the human construction of “better” theory models in the first place. Whereas a natural science approach had taken the human capabilities for understanding theory models as fixed and given, the design science approach is intent on changing the human capabilities for creating understandable theory models. In this way, design science should precede any meaningful attempt at natural science, since design science sets the conditions and changes the ground on which our natural science takes place.

CONCLUSION

In this essay we have described a pilot research project. The pilot was originally intended to use our advanced simulation tools to test the limits of an individual’s ability to predict the ramifications of their own assumptions. This was an endeavor firmly rooted in the natural science, or behavioral science, paradigm (March & Smith 1995; Hevner et al 2004). What we uncovered, however, is that our assumptions about how those individuals represent and formulate those theories using the software were off the mark. Instead of thinking in terms of parsimonious systems that lend themselves to simulation, we found that people tended to overly-simplify, and occasionally overly-complicate, their models. These finding afforded us the opportunity to revisit the theoretical roots that motivated the software in the first place. We will now commence a new research program fully in the spirit of design science, and thus take a normative view and focus on writing software that enables managers to create better theory models.

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