Theory Development in Design Science Research:  
Anatomy of a Research Project

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“Theories are practical because they allow knowledge to be accumulated in a systematic manner and this accumulated knowledge enlightens professional practice” (Gregor, 2007).

Abstract

The common understanding of Design Science Research in Information Systems (DSRIS) continues to evolve. Only in the broadest terms has there been consensus: that DSRIS involves, in some way, learning through the act of building. However, what is to be built – the definition of the DSRIS artifact – and how it is to be built – the methodology of DSRIS – has drawn increasing discussion in recent years. The relationship of DSRIS to theory continues to make up a significant part of the discussion: how theory should inform DSRIS and whether or not DSRIS can or should be instrumental in developing and refining theory. In this paper we present the exegesis of a DSRIS research project in which creating a (prescriptive) design theory through the process of developing and testing an IS artifact is inextricably bound to the testing and refinement of its kernel theory.
1. Introduction

In this brief paper we describe an in-progress information systems design science research project that aims to create a (prescriptive) design theory for a class of artifacts. Several phases of the project are informed by kernel theory (theory from other fields) and the project in turn will refine that theory into a mid-range DSRIS theory (Merton, 1968, Markus and Lee, 2000) that is more directly applicable to information systems development. The paper is illustrative rather than prescriptive: there are few ‘shoulds’ or ‘oughts’, but rather a demonstration of the productive relationship that can be developed between design science research, with its principle stress on design theory, and kernel theory. In order for the paper to serve as an “existence proof” of the potentially close relationship between design science research and kernel theory it must accomplish two things: first it must demonstrate the pedigree of the project as a true act of design science research; we have tried to do this without being overly pedantic. Second, it must demonstrate the relationships between mid-range DSRIS theory, the kernel theory from which it was refined, and the research conducted in betterment of IS artifact design.

In the next section of the paper (Section 2) we provide a brief overview of the variant viewpoints on the role of theory in DSRIS. In Section 3 we outline an in-progress DSRIS project and its kernel theory. It sets out details of the research design and demonstrates the potential of the research artifact for refining applicable kernel theory into mid-range DSRIS theory. Section 4 concludes by abstracting from our specific research project to a general discussion of the potential of DSRIS for theory development. Beyond that, we propose that “kernel theories” from other fields are often so narrowly derived as to be more suggestive than useful as given, and that refinement of the theory in the act of development is required to give the theory direct applicability to IS design efforts (Carroll and Kellogg, 1989).

2. Theory in DSRIS: What does it mean?

A number of positions have been stated with respect to the use and development of theory in DSRIS. Classifying these positions is made more difficult by the different meanings attached to the term “theory” by different writers. Gregor (2006) sets forth a taxonomy of five different types of theory in use within the field of Information Systems: (1) theory for analyzing, (2) theory for explaining, (3) theory for predicting, (4) theory for explaining and predicting and (5) theory for design and action. She notes, and we strongly concur, that in DSRIS writings and discussions of theory, attributes of the types in her taxonomy are frequently blended. In fact, as Gregor states, Iivari’s (1986) three category taxonomy of theory: conceptual, descriptive, and prescriptive, spans her categorization. In the hopes of simplifying matters for this paper, we have chosen to use a two-category taxonomy, very similar to that expressed in Walls, et al. (1992, 2004) and Nunamaker, et al. (1991)\(^1\):

1. “Kernel theories” which frequently originate outside the IS discipline and suggest novel techniques or approaches to IS design problems. The term and meaning are derived

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\(^1\) In addition to having a long history in the DSRIS foundational literature the two category taxonomy we use accords well with the distinction between explanation and prescription which is at the heart of many philosophies of design.
directly from Walls, et al. (1992, 2004); many kernel theories are “natural science” or “behavioral science” theories that explain and predict.


The DSRIS project we describe in this paper uses and refines both types of theory as it aims to create a design theory for a new class of artifact. This is somewhat unusual and a brief overview of the positions set out for the use of theory (of any type) within DSRIS will situate our approach. Table 1 below shows some of the influential writing on DSRIS and the actions and uses each paper proposes for each of the two types of theory.

<table>
<thead>
<tr>
<th>Discussion</th>
<th>Kernel theory activities</th>
<th>Design theory activities</th>
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<tbody>
<tr>
<td>Nunamaker, et al., 1991</td>
<td>kernel theories advise design solutions; possibility of refinement or development</td>
<td>DSRIS research creates design theories</td>
</tr>
<tr>
<td>Walls, et al., 1992, 2004</td>
<td>kernel theories advise design solutions</td>
<td>DSRIS research creates design theories – design theory is the primary output of DSRIS research</td>
</tr>
<tr>
<td>Simon, 1996</td>
<td>kernel theories advise design solutions; possibility of refinement or development</td>
<td>DSRIS research creates design theories; prescriptive design theories can revitalize b-schools</td>
</tr>
<tr>
<td>Orlikowski and Iacono, 2001</td>
<td>posed as a possible distraction to full attention to the IT artifact itself</td>
<td>seem to use the term ‘design theory’ in a broader sense than just prescriptive ‘models’- explanatory theories of and about design as well as theories of artifact construction</td>
</tr>
<tr>
<td>March and Smith, 1995</td>
<td>Seems to relegate kernel theory refinement to natural science. “Rather than posing theories, design scientists strive to create models, methods and implementations that are innovative and valuable.”</td>
<td>Our interpretation is that March and Smith’s use of the terms ‘model’ and ‘method’ – specified as desirable outputs for DSR – span the meaning of the term ‘prescriptive design theory’</td>
</tr>
<tr>
<td>Venable, 2006</td>
<td>[termed Solution Space and Problem theories] advise IS design at multiple levels; refinement or development of theories possible and beneficial</td>
<td>[termed Utility Theories] can emerge from a DSR effort at multiple levels</td>
</tr>
<tr>
<td>Hevner, et al., 2004</td>
<td>“… results from reference disciplines provide foundational theories…” (p. 80). Seems to relegate foundational theory refinement to behavioral IS research.</td>
<td>“prescriptive theories” [for artifact construction] are outputs of DSRIS (p. 77)</td>
</tr>
<tr>
<td>Vaishnavi and Kuechler, 2004</td>
<td>stress that one of the significant attributes of DSRIS is the ability to proceed in the absence of a theoretical basis; otherwise, as Venable, 2006</td>
<td>operational principles [for artifact construction] (Dasgupta, 1996, Purao 2002) can emerge at multiple levels</td>
</tr>
<tr>
<td>Goldkuhl, 2004</td>
<td>kernel theories provide theoretical grounding for the artifact (highly desirable)</td>
<td>“Design theory is considered as practical knowledge used to support design activities.”</td>
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</table>

A majority of the papers that discuss theory in the context of DSRIS understand design theory as a prescriptive statement that is a significant, perhaps the most significant, output of the research effort. Many papers also discuss kernel theories, but a majority of them consider this type of theory to be only advisory to the design effort. To the best of our knowledge only Venable (2006), Vaishnavi and Kuechler (2004) and Simon (1996) [in our interpretation] discuss the position taken in this paper, that kernel theories can both inform DSRIS efforts and that they can in turn be refined and developed by DSRIS. Figure 1 (Venable 2006) shows the relationships between DSRIS activities and theory development that we assume to exist in the discussions of our example project.

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2 Table 1 is far from complete. A fuller treatment of the literature on theory in DSRIS might begin with Venable, 2006, Gregor and Jones, 2007 and Kuechler and Vaishnavi, to appear.
Mid-range IS theories were not discussed in the preceding section on theory in prior DSRIS literature because they receive no mention in that literature. To the best of our knowledge this paper is the first to discuss mid-range theories in the context of DSRIS. In fact, while figuring prominently in the fields of sociology (where the idea originated), health care and management, discussion of mid-range theory seems absent from IS literature save for Nelson, et. al (2000) and the editor’s introduction to the issue containing that paper (Markus and Lee, 2000).

Elaboration on the relationship between design theories, kernel theories, mid-range theories and the DSRIS process are shown in Figure 2. The basis for Figure 2 is Goldhuhl’s (2004) graphical clarification of the logical relationships between prescription and explanation in the design process. To that starting point we have added the text highlighted in gray and the relations specified by dotted lines. Explanation has been identified with *kernel theories*; note that kernel theories inform both the effect we seek in the artifact (the “Goal”) as well as suggesting the “Prescribed action.” Prescription has been identified with *design theories*, and we have added two relationships: (1) the loop from artifact to empirical evidence\(^3\) that takes place during the evaluation of the artifact, and (2) the effect of this evidence on the explanatory statements which

\[\text{Figure 1. An Activity Framework for Design Science Research (Venable, 2006)}\]

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\(^3\) The box in Figure 2 labeled *Evidence* was termed *Empirical observations* by Goldkhu (2004). However, we are indebted to an anonymous reviewer for pointing out that simulation and mathematical proof are common means of validating DSRIS artifacts, and the term *Evidence* more fully encompasses the output of the range of empirical validation methods.
“can be revised to accord with” the observations of the artifact that take place during evaluation – observations which expose the theories in situ.

A final addition to the Figure, *Mid-range theories*, is depicted at a level that spans explanatory kernel theories and highly prescriptive design theories. The *Evidence* coming from the design and evaluation of the artifact refines the kernel theories. The environment of the design evaluation more tightly scopes the original theory(s). The net result is a mid-range theory that, because of its tighter scope and additional information content, is much more easily extrapolated to design prescription than the kernel theories from which it was derived.

In the next section we first elaborate on the phases of a design project during which the relationships shown in Figure 2 actually take place, and then describe the concrete design prescriptions and goals suggested by the kernel theory – by way of mid-range theory - for our project.

3. A Theory-Refining DSRIS Project

The activities of many design science research projects group naturally into phases such as those illustrated in Figure 3, which is similar to but more granular and directive in its description of project phases than Figure 1. However, just as in Figure 1, all research phases are potential
opportunities for the development and refinement of kernel theory, mid-range theory and design theory.

Background – Awareness of Problem

According to guidelines in Hevner, et al. (2004) a design science research project seeks a solution to a real-world problem of interest to practice. This was certainly true of our project which originated in the continued interest of the industry advisory board of one of the authors’ (IS) department in business processes – specifically in courses and research to support business process (BP) design, change, and management. After reviewing several cases supplied by the advisory board it became obvious that even though the initiation and high level design of many business processes is performed by non-IT personnel, the steps of the design process and the associated problems are very similar to those found in IS design. The problem that became the focus of our DSRIS effort was the sub-optimal design of business processes due to the lack of incorporation of soft-goal information into the final designs.

With further investigation we saw that not only were the activities such as requirements gathering and project management similar in IS and BP design, but also that the tools were similar. Many BP design efforts are supported by BP design software that represents the design in a graphic notation, frequently the emerging standard: BPMN (business process modeling notation). Sub-optimal design of IS due to lack of incorporation of soft-goal information is a problem that has been researched in both information systems and computer science (Mylopoulos et al., 1992). Many of the approaches to solving the problem in IS/CS have focused on the creation of notations to represent the constraint and soft goal information for the project. While promising, none of the suggestions from research to date has been widely adopted. However, prior research in the IS/CS domain did help to refine our problem statement to a design research question: How could business process modeling notations be enhanced to make soft-goal information more salient and more likely to be incorporated in final BP designs?

Suggestion

In this phase of a design science research project various approaches to the problem, informed by prior research on related issues, were worked out as “thought experiments” to explore the feasibility of each approach (Vaishnavi and Kuechler, 2007). It was at this point that “kernel theories” entered our design process. First, we reviewed the IS research on conceptual modeling and adopted the concepts and vocabulary from earlier research on design notation (Wand and Weber, 2002). Instead of speaking of process drawings we started referring to conceptual model scripts expressed in a notational grammar. We also became familiar with research guidelines for assessing the effectiveness of different conceptual models (Parsons and Cole, 2005).

Then, as we reviewed prior approaches to the problem of soft-goal “leakage” from system designs we saw that all of them focused on capturing soft-goal information in some form of graphic notation. Intuitively it seemed this effort might be misdirected. Based on 20+ years of IS industry development experience we wondered if the real problem was not capture and representation of soft-goal information – in most cases the information was available in the original requirements notes – but rather in making that information more immediately available
and especially more salient to the designer. Further, as we thought through different soft-information representations of our own, it seemed that a graphic representation of soft or contextual information was the wrong approach. We began to build the position that the highly qualitative, sometimes political, frequently ambiguous nature of soft information was best captured by textual narrative rather than graphics.

At this point, hoping to better understand why some concepts are more salient than others, we began to investigate problem solving cognition and came upon our “kernel theory” – actually a related set of theories from cognitive, educational and social psychology that described and explained how varying the presentation of information could enhance or diminish information salience and thus problem solving capabilities. One of our key papers, Zukier and Pepitone (1984) describes how the “base rate problem” made famous by Tversky and Kahneman (1981) and originally viewed as a “flaw” in human reasoning could be eliminated by reframing the problem. When the same information that people ignored when presented as numeric abstractions was presented as part of a story, the information was correctly incorporated into the solution of the problem. Another researcher exploring cognitive mechanisms involved in solving word problems effectively duplicated Zukier and Pepitone’s results and showed the importance of contextual information (especially intentional information) on eliminating “framing issues” in problem solving (Jou et al., 1996).

In consideration of these experimental results we came to believe a possible means to make soft-goal information more salient to designers would be to induce, by means of a novel conceptual

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*Figure 3. Reasoning in the Design Research Cycle*4

(extended from Vaishanvi and Kuechler, 2004)

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4 Adapted from Takeda, et al. (1990).
modeling grammar(s), a mode of cognition psychologists term “narrative thinking.” The alternative mode of cognition, “propositional thinking” tends to ignore problem irregularities (such as soft information!) and has been shown to be promoted by attention to abstract, diagrammatic problem representations. For convenience we refer the web of more granular theories that underpin narrative and propositional thinking as modal cognition theory (Zukier, 1986) and we refer to the research support for this kernel theory henceforward as the “narrative vs. propositional thinking” literature.

Further investigation revealed a parallel theoretical development from educational psychology that was also concerned with improving the mental models formed during the presentation of descriptive information: multi-media comprehension. Theoretical research in this field confirmed the cognitive effects from the narrative vs. propositional thinking literature and provided further vocabulary and high-level constructs for the project (Mayer and Jackson, 2005). Education design papers from this field suggested specific information presentation techniques for achieving enhanced cognitive models (Seufert, et al., 2007; Lewalter, 2003) and more directly influenced both our grammar design and the design of the presentation software.

The “kernel theories” we had adopted suggested directions for a design solution to our research problem but, having been taken from social, cognitive, and educational psychology they gave no specific prescriptions as to how the information could be used in the context of IS/BP modeling. First, the experimental results that grounded the theories were obtained in carefully controlled laboratory situations. To be useful in a working IS design the effects shown for narrative thinking would have to be demonstrated to be robust enough to give meaningful results in a far more complex environment. Second, the modes of presentation are different for our design environment than for the prior research in narrative vs. propositional thinking. Prior research used (1) narrative expression of information and (2) numeric/narrative presentation as the two treatments in its experiments. Third, the kernel literature has yet to resolve some of its theoretical conflicts.

Our design attempts to induce “narrative thinking” by incorporating textual representation of soft information into a graphic design notation via a software artifact. Thus, whether our final artifact is successful or not in achieving its design goals, its development will of necessity yield a substantial amount of information about the extensibility, limits, and conditions of use of our kernel theories. When appropriately formulated and presented, this new information forms the

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5 Philosophers of science have observed that in many fields a “theory” is a nomothetic web of propositions and sub-theories (Lakatos, 1978) rather than the narrower logical definition of theory set forth by Popper (1980). Modal cognition theory is an interlaced network of cognitive bias theories (Tversky and Khaneman, 1981), social judgment theory (Ajzen, 1977), script theories of sensemaking (Schank and Abelson, 1977), behavioral decision theory (Einhorn and Hogarth, 1981) theories of analogical thinking, Gentner, 1983) and more.

6 We found it interesting that the two literatures, “narrative thinking” and “multi-media presentation,” while seeming to us to explore very similar areas, did not cite each other.

7 Much of the recent literature in multimedia comprehension is involved with testing the net effect of two conflicting cognitive mechanisms, each with its own experimental support: cognitive load theory and coherence formation theory (Mayer and Jackson, 2005). Cognitive load theory predicts better learning from leaner presentations. Coherence formation theories predict better and deeper learning and more skill transference from richer (greater information content) presentations. The not uncommon conflict of results from grounding [kernel] literatures is still more evidence of the need to generate mid-range theory and its attendant constructs from kernel theory for DSRIS projects.
grounding of a theory of grammatical element salience in conceptual modeling (GES), a mid-level DSRIS theory with two characteristics: (1) the power to explain salience in the context of conceptual modeling and (2) far greater facility for extrapolation to specific design criteria than the kernel theories from which it was derived.

Development

It is at the development phase of a design research project that the tentative direction(s) for artifact generation explored in the suggestion phase are made concrete through construction and iterative refinement (Vaishnavi and Kuechler, 2007). Two interrelated artifacts emerged from the suggestion phase: (1) a novel dual grammar conceptual modeling technique and (2) a software modeling tool for the presentation of the process models (scripts).

The initial design for the conceptual modeling technique was derived from the statement of modal cognition theory: the mode of cognition termed “narrative thinking” gives rise to “story like” mental models that both readily incorporate and make salient non-regular information such as soft-goals. Therefore a business process model that stimulated narrative thinking could improve process designs. However a large part of the “design problem” of this research – the mapping from suggestion to a workable artifact – was to develop a modeling technique that maintained the conciseness and precision of graphic representations while simultaneously promoting a mental model that kept soft-goals salient. We decided to develop a dual grammar process modeling technique that used BPMN for the graphic representation combined with “micro-rationale” narratives; these concisely explained and gave context to the graphics by being integrally linked to related, small portions of the BPMN diagram.

The initial design for the software presentation artifact (essentially process modeling and documentation software) was informed by empirical studies of programmers in action as well as our kernel theory. From theoretical considerations we believed appropriately presented narrative about a graphical model of a process could enhance the formation of the mental model of the process. However, empirical studies of programmers have shown that diagrammatic representations of systems become the dominant documentation for a system during the later phases of design. The narrative requirements documents which contain the soft-goal information are rarely consulted (Davies, et al., 2006; Lethbridge, et al., 2003). The failure of many designs to incorporate soft information is de facto evidence that graphic representations also disproportionately influence initial cognitive model formation of the systems. Thus, the design of the presentation software focused on how to insure that the micro-rationales were attended to so that they could have the desired effect. When appropriately articulated these design constructs are available for incorporation into the GES theory.

Since prior process modeling software was available to serve as an example, prototyping of the presentation software proceeded fairly rapidly using web-development technologies. Prototyping the modeling technique and testing the software required content. We required cases that were concise enough to be used in an evaluation session of reasonable duration, did not require uncommon domain information on the part of the user, that were realistic and that contained mission-critical soft-goal requirements. The construction of such cases and the associated narrative and graphic descriptions of them occupied a significant amount of time. Eventually we
entered the pilot phase of our evaluation with three cases derived from real-world process implementations.

**Evaluation**

In a DSRIS project, the research process frequently iterates between Development and Evaluation phases rather than flowing in waterfall fashion from one phase into the next (Kuechler, Vaishnavi, and Petter, 2005). The evaluation of our artifacts, as for most DSRIS that deals with human-artifact interaction, took the form of an experiment.

Iteration between design (development) and evaluation (experiment) is one significant difference between design science research and “natural science” or theory-driven “behavioral science” experimentation. In natural science research the experimental procedure and apparatus are (ideally) constructed in such a way as to minimize confounds that might interfere with clear interpretation of the results; theory is either supported or disconfirmed. In design science research both the artifact and the experimental setting are intentionally complex (and thus confounded) in order to develop methods and artifacts that are useful in practice. Due to the confounded nature of the observations gained in the evaluation phase of a DSRIS effort it is difficult if not impossible to disconfirm a theory. However as noted by other researchers, the relation of a designed artifact to theory is extension and refinement of the theory rather than disconfirmation (Carroll and Kellogg, 1989). This fundamental difference encourages the iteration between design and evaluation that would be considered improper “fishing for data” in a natural science experiment.

Though not the focus of this paper, a brief description of the experimental design (evaluation framework) is necessary to understand the evaluation process:

MBA and MSIS students with more than 5 years of work experience are chosen as subjects. We evaluate the modeling technique and presentation software using the presence or absence of the treatment. Process designs are presented to subjects using graphical display and separate “design notes” (no treatment) or using the linked dual grammar model (treatment). Each subject is presented with two versions of a process design: original and changed. The changed process eliminates one or more critical soft-constraints. The subjects are to determine whether or not the changed process “is effective for the company.” Subjects are trained to “think aloud” as they reason through answering the question and their concurrent verbal protocols are recorded. The software, in addition to presenting the process design models, tracks the information the subjects choose to view.

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8 Hevner, et al. (2004, p. 89) term this iteration the “generate/test” cycle.
9 Both presentations make available identical information at very similar levels of convenience-of-access. We have followed guidelines for cognitive model experimentation set out in Parsons and Cole (2005) to the degree possible.
10 We believe the external validity of the experiment is strengthened by the nature of the subjects and procedure. Ninety percent of our MSIS student subjects are full time IT professionals, many with over 15 years of industry experience. We have endeavored to make the experimental procedure realistic by attempting to emulate the “Hey, Ralph, can you take a quick look at this and tell me what you think?” task that in our experience is quite common in industry.
In the course of our study (still ongoing as of this writing) we have cycled between Development and Evaluation phases of the DSRIS process numerous times in order to:

- Reprogram the software to force reference to the micro-rationales during treatment (we thought we had done so in the initial design but subjects are exceptionally devious at frustrating experimental expectations)
- Reprogram the software to eliminate display “quirks” that had become transparent to us but were distracting to subjects
- Redefine micro-rationales to supply broader context
- Rewrite the modeling scripts (as a result of the above refinement)

At this point we do not have enough data to claim statistical significance however, the results to date have been encouraging. We have seen evidence of the development of different cognitive models in treated and untreated groups both in analysis of the verbal protocols and in better time-to-answer and correctness-of-answer scores for the treatment group. The pilot findings that drove redesign of the preliminary artifact are available also for incorporation into still nascent GES theory.

4. Summary

The in-progress research project described in this paper is an example of design science research that can yield not only a prescriptive design theory for a class of artifacts, but can also refine and extend the kernel theory that suggested the novelty in the artifact design approach. The results of refinement are rarely articulated and formulated in DSRIS or any other type of IS research project. However when the novel information from artifact design and evaluation are captured and articulated, they can form the basis of a mid-range theory, in this specific case, a theory of grammatical element salience in conceptual modeling (GES). The research meets the guidelines for design science research in IS set out in Hevner, et al. (2004) and also follows one of the artifact evaluation approaches suggested in that paper: a controlled experiment.

With reference to Figure 3, kernel theories from outside IS entered the design science research process at two points. Theories of “narrative thinking,” a mode of cognition receptive to unpatterned information, led to a novel design approach to a conceptual modeling grammar in the Suggestion phase. Theories of multi-media comprehension from educational psychology informed both the grammar design at the Suggestion phase and the design of the software artifact in the Development phase. Since the evaluation of both research artifacts is accomplished with a controlled experiment, refinement of the kernel theories into the GES theory - as embedded in the artifacts – is both statistically valid and rigorous within the limits of the design science paradigm. The paradigm necessarily introduces confounds into the interpretation of results, however, it also produces extension and refinement of the theories in the event of either success or lack of success of the artifacts.

If the artifacts are successful, they ground the new mid-range GES theory and further experimentation in DSRIS projects can extend and refine the theory. The GES theory is much more readily adoptable into future DSRIS projects than were the kernel theories from which it was derived. If the artifacts are unsuccessful they suggest limitations to the kernel theories which
were not obvious in the original theory statements. For example, lack of significant results for the artifacts in this project suggest the induction of narrative thinking is more difficult when graphical representations supply much of the information on a problem than when the information is supplied solely by narrative and numeric representations.

The DSRIS project presented in this paper is not unique in its ability to refine and extend kernel theory into mid-range DSRIS theory. In fact, we believe along with other authors (Venable, 2006; Carroll and Kellogg, 1989) that artifact design projects are the best possible opportunities for refining theory from other fields for use in IS. The nature of different research paradigms – natural and behavioral science vs. design science – makes it unlikely that theory from outside design science will be readily adaptable to artifact construction. Natural and behavioral science experiments take place in much more restricted environments than those for design science artifact evaluation and typically use different levels of analysis than DSRIS. Thus, almost all DSRIS projects using kernel theories inevitably refine and extend those theories. It is our hope that this theory refinement and extension can come to be widely acknowledged as a potential part of and benefit of the DSRIS process. Such acknowledgement would encourage the articulation, theoretic formulation and publication of DSRIS mid-range theories to the enhancement of all areas of IS research.
References


