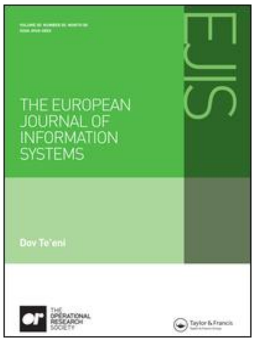


European Journal of Information Systems

ISSN: 0960-085X (Print) 1476-9344 (Online) Journal homepage: https://www.tandfonline.com/loi/tjis20

On theory development in design science research: anatomy of a research project

Bill Kuechler & Vijay Vaishnavi

To cite this article: Bill Kuechler & Vijay Vaishnavi (2008) On theory development in design science research: anatomy of a research project, European Journal of Information Systems, 17:5, 489-504, DOI: 10.1057/ejis.2008.40

To link to this article: https://doi.org/10.1057/ejis.2008.40

European Journal of Information Systems (2008) 17, 489–504

www.palgrave-journals.com/ejis

On theory development in design science research: anatomy of a research project

Bill Kuechler[1] and
Vijay Vaishnavi[2]

[1]Accounting and Information Systems, University of Nevada, Reno, NV, U.S.A.; [2]Computer Information Systems, Georgia State University, Atlanta, Georgia, U.S.A.

Correspondence: Bill Kuechler, Accounting and Information Systems, Mail Stop 026, University of Nevada, Reno, NV 9557-0205, U.S.A.
Tel.: +1 775 784 6910;

Received: 29 April 2008
Accepted: 8 September 2008

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 information systems artifact is inextricably bound to the testing and refinement of its kernel theory.
European Journal of Information Systems (2008) **17,** 489–504.
doi:10.1057/ejis.2008.40

Keywords: design science; theory building; mid-range theory; kernel theory; research methods; design theory

> Theories are practical because they allow knowledge to be accumulated in a systematic manner and this accumulated knowledge enlightens professional practice. (Gregor, 2006)

Introduction

In this paper, we describe an in-progress information systems (IS) 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 (frequently theory from other fields that intends to explain or predict phenomena of interest) and the project in turn will refine that theory into a mid-range design science research in information systems (DSRIS) theory (Merton, 1968; Markus & Lee, 2000) that is more directly applicable to IS 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 principal 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 among 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, we provide a brief overview of the variant viewpoints on the role of theory in DSRIS. This is followed by a section that outlines 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. In a separate section, we summarize theory development in the project to date. The paper's conclusion abstracts 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 & Kellogg, 1989).

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 IS: (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 Nunamaker *et al*. (1991) and Walls *et al*. (1992, 2004). 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:

1. 'Kernel theories' frequently originate outside the IS discipline and suggest novel techniques or approaches to IS design problems. The term and meaning are derived directly from Walls *et al*. (1992, 2004); many kernel theories are 'natural science' or 'behavioral science' theories of Gregor's (2006) 'explain' and 'predict' type.
2. 'Design theories' give explicit prescriptions for 'how to do something' and correspond almost exactly to the 'design theories' of Walls *et al*. (1992, 2004) and Gregor's (2006) 'design and action' theory type.

The DSRIS project we describe in this paper uses and *refines* kernel theory as it aims to create a design theory for a new class of artifacts. Refinement of theory in DSRIS 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 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 1 is far from complete. A fuller treatment of the literature on theory in DSRIS might begin with Venable (2006a), Gregor & Jones (2007), and Kuechler & Vaishnavi (2008).

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 of these 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 Simon (1996), Vaishnavi & Kuechler (2004), and Venable (2006a) (in our interpretation) discuss the position taken in this paper, that kernel theories can both *inform* DSRIS efforts and can in turn be *refined and developed* by DSRIS. Figure 1 (Venable, 2006a) shows the relationships between DSRIS activities and theory development that we assume to exist in the discussions of our example project.

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. Based on a search of IS literature databases, we believe this paper to be one of 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 & Lee, 2000). Merton's (1968) original description of mid-range theories is that they are explanatory theories but of a restricted scope and as such more readily suggesting actions for specific effects in applied fields. Gregor (2006), in a discussion of the breadth and focus of theories in IS, describes mid-range theories as leading to easily testable hypotheses. Note that kernel theories can be mid-range theories, albeit from different disciplines.

Elaboration on the relationship among design theories, kernel theories, mid-range theories, and the DSRIS process is shown in Figure 2. The basis for Figure 2 is Goldkuhl'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 relationships 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 evidence that takes place during the evaluation of the artifact, and (2) the effect of this evidence on the explanatory statements, which 'can be revised to accord with' the observations or logically demonstrated behaviors of the artifact that take place during evaluation – observations, which expose the theories *in situ* (Venable, 2006b).

Table 1 Kernel and design theories in DSRIS literature

Discussion	*Kernel theory conception*	*Design theory conception*
Nunamaker *et al*. (1991)	Kernel theories advise design solutions; possibility of refinement or development	DSRIS research creates design theories
Walls *et al*. (1992, 2004)	Kernel theories advise design solutions; govern design requirements	DSRIS research creates design theories – design theory is the primary output of DSRIS research
March & Smith (1995)	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'	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', at least in the fairly narrow meaning given to ISDT in Walls *et al*. (1992). See the discussions of research outputs in Section 3.1 of their paper
Simon (1996)	Kernel theories advise design solutions; possibility of refinement or development	DSRIS research creates design theories; prescriptive design theories can revitalize b-schools
Orlikowski & Iacono (2001)	Posed as a possible distraction to full attention to the IT artifact itself	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
Goldkuhl (2004)	Kernel theories provide theoretical grounding for the artifact (highly desirable)	'Design theory is considered as practical knowledge used to support design activities'
Hevner *et al*. (2004)	'… results from reference disciplines provide foundational theories…' (p. 80). Seems to relegate foundational theory refinement to *behavioral* IS research.	'Prescriptive theories' [for artifact construction] are outputs of DSRIS (p. 77)
Vaishnavi & Kuechler (2004)	Stress that one of the significant attributes of DSRIS is the ability to proceed in the absence of a theoretical basis; otherwise, as Venable (2006a)	Operational principles [for artifact construction] (Dasgupta, 1996; Purao 2002) can emerge at multiple levels
Venable (2006a)	[Termed Solution Space and Problem theories] advise IS design at multiple levels; refinement or development of theories possible and beneficial	[Termed Utility Theories] can emerge from a DSRIS effort at multiple levels

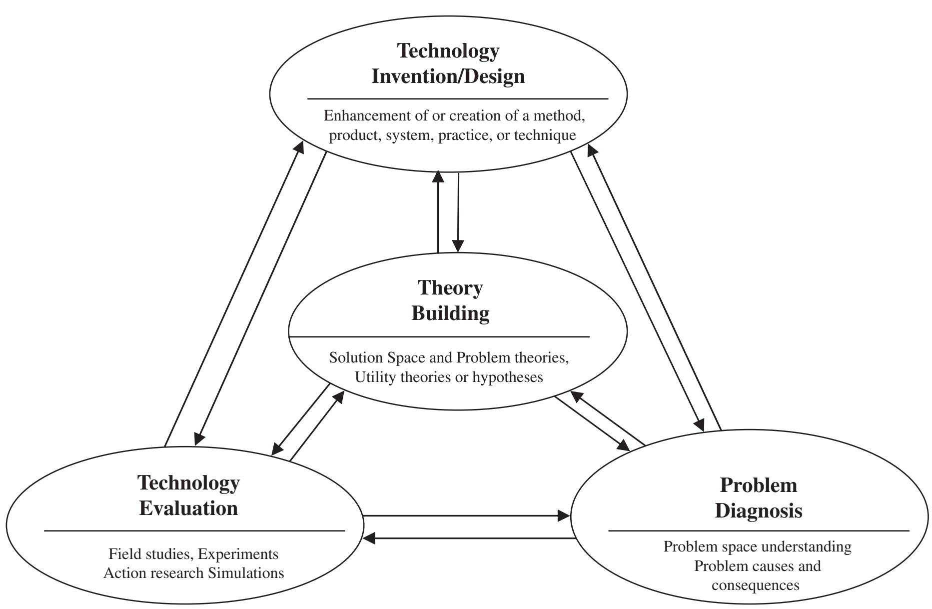


Figure 1 An activity framework for design science research (Venable, 2006b).

A final addition to the figure, *mid-range theories*, is depicted as a conceptual bridge between high-level explanatory kernel theories and highly prescriptive design theories. Through the praxis of the DSR project, new empirical knowledge and knowledge from kernel theories is translated from the kernel domain to become

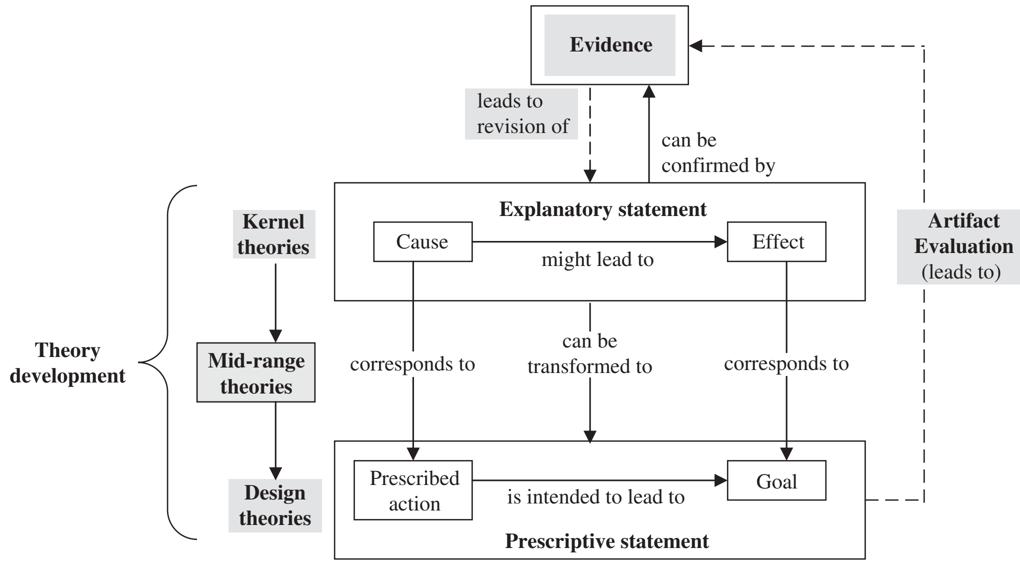


Figure 2 Relationships among kernel theory, mid-range theory and design theory, and the design process (modified from Goldkuhl, 2004).

unique IS 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.

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 in 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 suboptimal design of business processes due to the lack of incorporation of soft context information into the final designs.

Soft context information is our term for information about the operational context of a system or process that has two characteristics:

1. It is frequently social or organizational information, that is, difficult to capture objectively with common specification notations such as DFD, business process modeling notation (BPMN), or UML.
2. [It] '… serve[s] as selection criteria for choosing among myriads of decisions. Errors of omission [of this information] are among the most expensive and difficult to correct once the IS has been completed' (Mylopoulos *et al*., 1992).

We chose 'soft context' information as an umbrella term for the contextual information referred to in the literature by (unfortunately) multiple terms including *context information* (Gause, 2005), *soft constraints* (Stefansen & Borch, 2008), *nonfunctional requirements* (Cysneiros *et al*., 2001), and *requirements perspectives* (Nissen *et al*., 1996). An example of soft context information from the pool of process scenarios we prepared for our artifact evaluation is given in Appendix A.

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

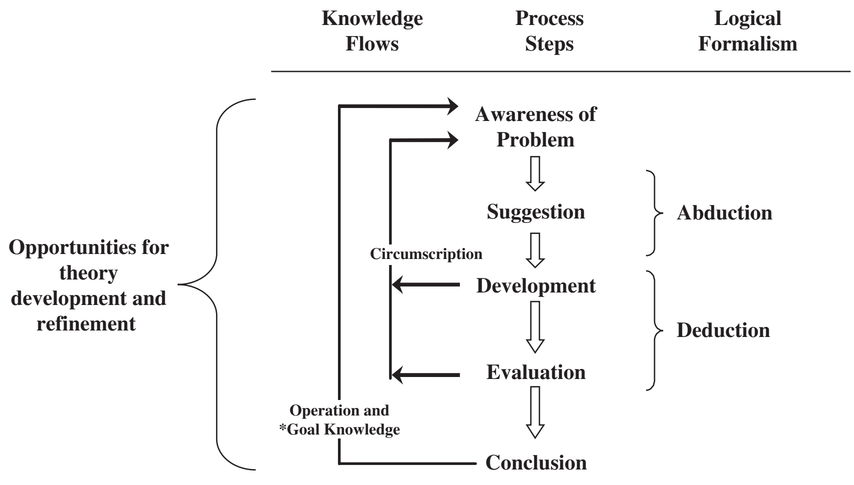


Figure 3 Reasoning in the design research cycle (extended from Vaishnavi & Kuechler, 2004 as adapted from Takeda *et al.*, 1990). Note: *An operational principle can be defined as 'any technique or frame of reference about a class of artifacts or its characteristics that facilitates creation, manipulation, and modification of artifactual forms' (Dasgupta, 1996; Purao, 2002).

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. Suboptimal design of IS due to lack of incorporation of soft context information is a problem that has been researched in both IS and computer science (Mylopoulos *et al.*, 1992). Many of the approaches to solving the problem in IS/CS have focused on the use of graphic notations to represent the soft context information for the project. Possibly the most widely known form of this type of notation is the Ishikawa diagram used in multiple fields to represent quality (a decidedly soft constraint) issues. One of the most common notations in the computer science subfield of requirements engineering is the i* model (Yu & Mylopoulos, 1994; Yu, 1995). An excellent example of its use in representing soft context information is given for an air traffic management case study in (Maiden *et al.*, 2005). i* is a formalization of 'influence diagrams' used in many fields to represent webs of interrelated qualitative influences in an environment. Examples of influence diagrams and an example of the i* notation from Maiden *et al.* (2005) are given in Appendix B. Other notations sometimes used to represent soft context are *hierarchical AND/OR graphs* (Cysneiros *et al.*, 2001) and graphic representations of *contribution structures* (Gotel & Finkelstein, 1995); examples of these notations are also given in Appendix B.

None of the suggestions from research to date has been widely adopted in industry (Lethbridge *et al.*, 2003; Davies *et al.*, 2006), and as a glance at Appendix B will show, the formal notations proposed would be highly complex for most real-world processes and would require some training in first-order predicate logic to be developed or understood. This creates a formidable barrier to their use by business persons in process design. Most significantly, the creation of graphic representations of soft context information presumes the information has been previously *noted* and *understood as significant* by project analysts – an assumption, which our problem statement indicates is not the case. However, prior research in the IS/CS domain did help to refine our problem statement to a design research question: How could BPMNs be enhanced to make soft context 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, are worked out as 'thought experiments' to explore the feasibility of each approach (Vaishnavi & Kuechler, 2007, pp. 20, 132–133, 139). 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 & 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 & Cole, 2005).

Then, as we reviewed prior approaches to the problem of soft context 'leakage' from system designs we saw that all of them focused on capturing soft context information in some form of graphic notation. Intuitively it seemed that this effort might be misdirected. Based on 20+ years of IS industry development experience we wondered if the real problem was not the capture and representation of soft context 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 & Pepitone (1984) describes how the 'base rate problem' made famous by Tversky & 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; Kuechler & Vaishnavi, 2006).

In consideration of these experimental results we came to believe that a possible means to make soft-goal information more salient to designers would be to induce, by means of a novel conceptual modeling grammar(s), a mode of cognition that 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 information presentations such as numeric and diagrammatic representations (Zukier & Pepitone, 1984; Zukier, 1990). For convenience we refer to 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 development in educational psychology that was also concerned with improving the mental models formed during the presentation of descriptive information: multimedia comprehension. This subfield of educational technology has both theoretical and empirical branches that illustrate the relation between theoretical and prescriptive statements (Goldkuhl, 2004; Figure 2) in yet another domain. The theoretical work in this field proposes high-level explanatory statements concerning learning from computer mediated information presentations: text combined with various graphics that illustrate the concepts contained in the text. The results of low level experiments in this literature provided support for broad explanatory statements that confirmed the cognitive effects from the narrative *vs* propositional thinking literature and provided further vocabulary and high-level constructs for the project (Mayer & Jackson, 2005).

In the prescriptive branch, educational technology design papers sought to transition from theoretical statements of multimedia cognition to specific techniques for the most effective presentation of different types of material – laws of rectilinear motion, for example. These papers prototyped mixed narrative and graphic presentation techniques and evaluated the resulting cognitive models. In Seufert *et al.* (2007) several display techniques were used in the context of understanding the physiological effects of vitamin C. First, hyperlinked text and an illustration were displayed simultaneously. When the hyperlinks were clicked, an arrow appeared at the appropriate portion of the illustration. In a second study, four different representations of related material – text, graphs, tables, and a chemical formula – were used. Subjects could move between the presentations, but only one representation was on-screen at a time. In each case understanding was measured by a post-session objective quiz. In Lewalter (2003), the information content was the phenomena of gravitational lensing and the presentation techniques were text and static illustration or text and animated illustration; both learning and learning strategies were assessed in this study. While not directly applicable due to the different media content and artifact intent, this literature 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 from 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. 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 & 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.

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 grounding of *a theory of grammatical element salience in conceptual modeling (GESCM)*, 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 & 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 nonregular information such as soft context. Therefore a BP 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 context salient. We decided to develop a dual-grammar process modeling technique that used BPMN for the graphic representation combined with textual process context descriptions and '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 (Lethbridge *et al.*, 2003; Davies *et al.*, 2006). The failure of many designs to incorporate soft context 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 process description narrative and especially the micro-rationales were attended to so that they could have the desired effect. Since prior process modeling software was available to serve as an example, prototyping of the presentation software proceeded fairly rapidly using web-development technologies.

Micro-rationales are our term for short, concise statements of design rationale (Canfora *et al.*, 2000). They are linked to small, coherent portions of a process design (and associated graphic representation) and describe *why* the process segment was designed as it was. By definition, rationale statements are at a level of abstraction above the mechanical description of the process; our BP micro-rationales were at a business evaluative level or social/cultural organizational level. In order to best help induce a narrative mode of thought they were expressed as complete, syntactically correct sentences, and were woven into a longer 'story' or textual description of how the process as a whole functioned. Micro-rationales and process description text are the first grammar of our hybrid modeling notation; BPMN graphical constructs are the second.

Our initial prototype naively assumed that if we presented a BPMN process diagram with some of its graphic elements set up as readily discernable hyperlinks to textual process description and micro-rationales (which would display on the other side of the screen) that users would seek all available information and pursue the links. We were wrong. The majority of our pilot study subjects attempted to answer questions about the operation of the process without viewing any of the narrative components (working from the diagram only) *even though they had been instructed in the use of the links and advised of their value, that is, that they were responsible for causing the display of information that was not available in the diagram*. Using rollovers in place of links was equally unsuccessful. While these results were fascinating in themselves, we truly wished to test our primary hypotheses – that narrative mode thinking could be induced by a presentation artifact and that it would result in superior reasoning about process designs – and so we ultimately designed the display software to *force* a sequential viewing of process text description and micro-rationales followed by their related process diagram 'slices.' Screen shots of the final prototype and additional description are given in Appendix C.

When appropriately articulated, the design constructs presented briefly in the preceding two paragraphs – dual-grammar modeling scripts, presentation technique, and empirical knowledge of user (designer) notation viewing preferences – are available for incorporation into the GESCM theory.

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, were realistic and contained mission-critical soft context 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 (see Appendix A).

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 *et al*., 2005). Hevner *et al*. (2004, p. 89) term this iteration the 'generate/test' cycle. 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. Owing 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 & 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.

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

> M.B.A. and M.S.I.S. students with more than 5 years of work experience were chosen as subjects. We evaluated the modeling technique and presentation software using the presence or absence of the treatment. Process designs were presented to subjects using either graphical display and separate 'design notes' (no treatment) or using the linked dual grammar model (treatment). Each subject was presented with two versions of a process design: original and changed. The changed process eliminated one or more critical soft constraints. The subjects were to determine whether or not the changed process 'is effective for the company.' Subjects were trained to 'think aloud' as they reasoned through answering the question and their concurrent verbal protocols were recorded. The software, in addition to presenting the process design models, tracked the information the subjects choose to view.

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 & Cole (2005) to the degree possible. We have striven to approximate *naturalistic evaluation* of the artifact (Venable, 2006a) and 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, we cycled between development and evaluation phases of the DSRIS process numerous times in order to

- Reprogram the software to force reference to the descriptive text and 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 process description narrative and micro-rationales to be clearer and to supply broader context. Again, things that were pellucid to us were shown by our pilot studies to need elaboration or rewording to be equally clear to our subjects.
- Rewrite the modeling scripts (as a result of the above refinements).

In fact, on two separate occasions when we believed ourselves to be through with our pilot study and thought we had begun the full experiment, it was necessary to make such significant changes to our prototype and our assumptions that we had to declare the results to that point part of the pilot, recruit more subjects and begin 'the actual experiment' again.

Using terminology from Walls *et al*. (1992) the goals of the development derive from the *meta-requirements* for the artifact. Our evaluation measurements then test the hypotheses that our *meta-design* has realized those goals. (We discuss design theory development more fully in the next section of the paper.) The primary goal for the project was to improve understanding of and reasoning about process models. In addition to better general understanding, we sought the specific improvement of increased salience during process modeling of critical 'soft context' information about the process that is difficult to capture in existing process modeling languages and thus is frequently overlooked.

Our evaluation observations were of two types: (1) Observations of understanding – the net effect of the artifact. Analysis of these data will tell us the degree to which the design goals had been achieved. (2) Observations of behavior – we will analyze these data in an attempt to understand how the net effects came to be and why they were as they were.

We discuss our observations of understanding first; these also fell under two different classifications: (1) Tests for surface understanding of the process – its mechanics, its flow, and the isolated functioning of its activities. (2) Tests for deeper understanding, which includes the interaction of the process with the critical organizational context in which it operates. In educational psychology what we term *deeper understanding* is sometimes called *transfer learning* (Cook *et al*., 2007).

Surface understanding was operationalized as objective questions about the process, for example, what flowed from activity A to activity B under what decision conditions. Deeper understanding was operationalized as: (1) The ability to assess the acceptability of changes to the process in the context described. (2) The ability to construct acceptable alternative changes to the process; changes that accomplished the same goal as the change presented in the session, and did not conflict with the soft or hard constraints presented in the process narrative. (3) The ability to mentally simulate the performance of the original and/or changed processes under new conditions suggested to the subject after they had been presented with both original and changed processes and had formed mental models of them. Further, we measured both types of understanding with short-term (in session) and long-term (1 week) tests.

We assessed behavior in three different ways. (1) We recorded what the subjects viewed by programming our presentation software to store the information objects subjects chose to view as described above. This information will tell us the amount of time subjects spent on each type of information, graphic or textual, the order in which they viewed information, etc. (2) We trained the subjects to speak aloud as they sought to understand the processes that were presented to them and recorded their verbal protocols. We will code these protocols to understand the different ways in which subject form cognitive models of processes under the two experimental treatments (Vans & von Mayrhauser, 1999). (3) We asked questions; about their confidence in their answers to questions under the two treatments and about their information preferences – graphics or narrative – in differing business situations.

As of this writing we have completed data gathering, have transcribed the protocols and have almost completed preliminary coding of the protocols. We have not begun formal analysis and so cannot claim statistical significance; however, preliminary observations 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 confidence, richer mental simulations, and objectively better correctness-of-answer scores for the treatment group. The pilot findings that drove redesign of the preliminary artifact are available also for incorporation into the still nascent GESCM theory.

Theory development

The following discussion consolidates the theory development that has taken place during the DR project to date. To maintain the focus of the paper on theory development rather than the actual artifacts and to keep the length of the paper within bounds we confine our discussion to theory statements concerning the display artifact only. Equally rigorous development for the dual-grammar conceptual model can also be presented.

First we present the constructs used to express our theoretical propositions (see Table 2). We use a table format since all of the constructs have been discussed at previous points in the paper. Second, we state and discuss propositions from our kernel theories: *modal cognition theory* and *multimedia comprehension* that seemed to have relevance to our design project. We then state and discuss the foremost proposition of the mid-range theory informed by our kernel theory, a *theory of GESCM*. We use the term 'informed' to make it very clear that the link from kernel to mid-range theory is *not* one of logical deduction or other rigorous, formal procedure, but rather is due to what has been termed the 'hypothetical/deductive' method (Baldwin & Yadav, 1994). The hypothetical/deductive method is the introspective explication of the results of the cognitive process of analogical reasoning (Gentner, 1983) from one domain to another, which we believe to be the basis of the kernel→mid-range inferences, followed by formal statement of these results. Lastly, we state and discuss the tentative propositions of a design theory for the display artifacts: the *process model presentation software*.

Theoretical constructs

Kernel theory propositions

- From the modal cognition literature:
  - The cognitive model formed from information about a situation can be made more receptive to social or 'soft' information by varying the mode of information presentation from abstract – propositional (numeric) to narrative (textual). (Note that a proposition of exactly this form can likely *not* be found in the literature. We have presented our interpretation, which at this point is quite informed. We have taken no liberties with matters of fact, but have 'repackaged' conclusions from the kernel literature to concisely state what was of interest to

Table 2 Theoretical constructs for kernel and mid-range theories

Construct	*Definition*
Mental model	The internal, cognitive model (in this case, of business processes) that contains the information about the model elements and their relationships
Modes of cognition	Modes of perceiving information that determine the types of information most readily acquired and the strength of relationships between information elements as mental models are formed
Surface understanding (of processes)	Understanding of the 'mechanics' of process elements – flows, actors, and decisions at an algorithmic level – excluding domain or context information
Deep understanding (of processes)	Surface understanding combined with knowledge of the context in which the process operates and the interactions, actual and potential, between the process and its environment
Soft context information	Organizational, cultural or political information about the actors or environment of a process that is difficult to capture in conventional process notations but that is frequently critical to the success of the process. In a medical informatics context, for example, the aversion of many older MD's to information technology is one example of soft context
Narrative (sometimes termed *text*)	Information in language form
Micro-rationales	Small concise narrative segments relating process details or context not found in diagrammatic representations, usually woven into a coherent 'story' about the process
Salience	In this context, the term denotes the degree of attention and significance given to different information elements of a conceptual model

us. The restatement also makes it easier to follow our development from one theory level to the next.)

- From the multimedia comprehension literature:
  - Richer cognitive models of physical processes that demonstrate greater transfer learning (across domains) result from mixed-media presentations of the processes, that is, text + illustrations, than from text or illustrations alone.

Mid-range theory propositions (A theory of *GESCM)*

1. In systems design a conceptual model can be used to concisely represent one or more important aspects of the system.
2. A system always operates in a context. Usually the grammar(s) for the conceptual model(s) of the system are optimized for the representation of a narrow range of system constructs. Specifically, these grammars are not well suited to representing organizational context information, especially when they are graphical in form.
3. Organizational context information can be expressed in narrative (language) form.
4. Virtually all business systems are artificial – they are designed and there are reasons called *design rationale* that describe why they are as they are. Design rationale also can be expressed in narrative form.
5. When conventional (narrowly focused) conceptual models for processes are linked in a designer's mental model to expressions of critical organizational context and design rationale, better design decisions are achievable.
6. Computer-based conceptual model design and display artifacts can be built that force attentional links between conventional conceptual model element displays and narrative information displays of organizational context and design rationale so as to facilitate the construction in the user of the artifact of mental models that link context information with the information captured by the conventional conceptual model.
7. The strongest and most useful overall mental model (conventional conceptual model and narrative components) will be produced when the narrative components are woven into a coherent (by basic literary standards) *story* rather than presented as separate, intelligible but logically unconnected text components. (This is one of the distinguishing features between a dual-grammar conceptual model and a simple annotated conceptual model graphic display.)

Note the conceptual 'leap' from kernel theory propositions to the primary propositions of GESCM. No existing research from the kernel fields allows us to draw propositions 6 or 7 above as *conclusions*. They are at best inductions and need to be tested. However, the propositions are much closer to the IS design domain than any of the kernel theories and *immediately suggest testable hypotheses where the tests are in the form of the evaluation of artifacts designed in accordance with the propositions*.

Design theory propositions In setting out the design theory (see Table 3) derived from our mid-range theory statement we continue to use the concepts – and for this section even the presentation format – from Walls *et al*. (1992, 2004). In developing our mid-range theory from our kernel theories we descended a level of abstraction; alternatively stated, the mid-range theory was more concrete. The kernel theories dealt with general cognitive abilities. GESCM applies these theories inductively to the more concrete realm of computer mediated conceptual models. Transitioning from mid-range to design theories, we become still more concrete. At the information

Table 3 Design theory for cognitively enhanced process model presentation software (format taken from Walls *et al*., 2004)

	Theory component	Description
Design product		
1.	Meta-requirements	Multiple types of process information: graphic representations of process mechanics, narrative representation of organizational context, and narrative representations of design rationale are presented to the user in a manner that induces linkages in the overall mental model of the process
2.	Meta-design	Graphic process representation components are displayed in logical sequence with linked narrative necessarily displayed before the subsequent or prior graphic component can be displayed
3.	Kernel theories	Modal cognition theory + multi-media comprehension theory
4.	Testable design product hypotheses	Users will develop richer cognitive models of business processes leading to better (re)design decisions
Design process		
1.	Design method	[a]
2.	Kernel theories	[a]
3.	Testable design process hypotheses	[a]The design process for the display software did not seem to us to be outside the state-of-practice for sophisticated educational or www-commercial software

[a]Walls *et al*. (1992, 2004) define a complete ISDT as possessing both a product and a process component. However, after much reflection we are unable to see that the process by which we designed our display artifact was novel in any meaningful way and have so noted in table.

systems design theory (ISDT) level the statements are scoped to computer software for *presenting graphic process models and related textual design rationale and context information*. We believe this is still at a meta-level appropriate for an ISDT; that is, it applies to a class of process model presentation artifacts and leaves the graphic portion of the grammar and many other important design features unspecified.

Conclusions

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 suggests the novelty in the artifact design approach. The novel information from artifact design and evaluation that we have captured and articulated forms the basis of a mid-range theory, *a theory of GESCM*. 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 multimedia 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 GESCM theory – as embedded in the artifacts – will be 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 will ground the new mid-range GESCM theory and further experimentation in DSRIS projects can extend and refine the theory. The GESCM 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 will 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 would 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 as it was in the kernel theory experiments.

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 (Carroll & Kellogg, 1989; Venable, 2006a) 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.

Acknowledgements

We are greatly indebted to the anonymous reviewers whose suggestions have greatly strengthened the paper. We especially appreciate the suggestion that what we originally referred to as *refinement of kernel theories* might in fact be the development of mid-range theory. A paper by the reviewer on this topic may well precede this paper to publication.

About the authors

Bill Kuechler is an associate professor of Information Systems at the University of Nevada, Reno. He holds a B.S. in Electrical Engineering from Drexel University and a Ph.D. in Computer Information Systems from Georgia State University. His two primary research themes are the cognitive bases of IS use, development and education, and interorganizational workflow and coordination. He has published in *MIS Quarterly*, *Communications of the ACM*, *IEEE Transactions on Knowledge and Data Engineering*, *Decision Support Systems*, *Journal of Electronic Commerce Research*, *IEEE Transactions on Professional Communications*, *Information Systems Management*, *Information Technology and Management*, *Journal of Information Systems Education*, *the proceedings of WITS*, *HICSS*, and other international conferences and journals. He is a member of AIS and ACM.

Vijay K. Vaishnavi is Board of Advisors Professor of Computer Information Systems at Robinson College of Business and Professor of Computer Science, Georgia State University. He holds a Ph.D. from Indian Institute of Technology, Kanpur and has conducted postdoctoral work at McMaster University, Canada. His research covers several areas including process knowledge management, semantic interoperability and information integration, web mining, interorganizational coordination, object modeling and design, and data structures. He has authored numerous research papers in these and related areas. The National Science Foundation and private organizations including IBM, Nortel, and AT&T have supported his research. His papers have appeared in *IEEE Transactions on Software Engineering*, *IEEE Transactions on Knowledge and Data Engineering*, *IEEE Transactions on Computers*, *SIAM Journal on Computing*, *Journal of Algorithms*, *MIS Quarterly*, *Decision Support Systems*, and several other major international journals and conference proceedings. He is an IEEE fellow, a member of the IEEE Computer Society, a member of the ACM, and a member of the AIS.

References

BALDWIN D and YADAV S (1994) The process of research investigations in artificial intelligence – an unified view. *IEEE Transactions on Systems, Man and Cybernetics* **25(5),** 852–861.

CANFORA G, CASAZZA G and DE LUCA A (2000) A design rationale based environment for cooperative maintenance. *International Journal of Software Engineering & Knowledge Engineering* **10(5),** 627–646.

CARROLL J and KELLOGG W (1989) Artifact as theory nexus: hermeneutics meets theory-based design. In *Proceedings of CHI '89* (BICE K and LEWIS C, Eds), ACM Press, New York.

COOK D, HOLDER L and YOUNGBLOOD C (2007) Graph-based analysis of human transfer learning using a game testbed. *IEEE Transactions on Knowledge and Data Engineering* **19(11),** 1465–1478.

CYSNEIROS L, LEITE J and NITO J (2001) A framework for integrating non-functional requirements into conceptual models. *Requirements Engineering* **6(2),** 97–115.

DASGUPTA S (1996) *Technology and Creativity*. Oxford University Press, New York.

DAVIES I, GREEN P, ROSEMANN M, INDULSKA M and GALLO S (2006) How do practitioners use conceptual modeling in practice? *Data & Knowledge Engineering* **58,** 358–380.

FICKAS S and HELM R (1992) Knowledge representation and reasoning in the design of composite systems. *IEEE Transactions on Software Engineering* **18(6),** 470–482.

GAUSE D (2005) Why context matters – and what can we do about it? *IEEE Software* **22(5),** 13–15.

GENTNER D (1983) Structure-mapping: a theoretical framework for analogy. *Cognitive Science* **7,** 155–170.

GOLDKUHL G (2004) Design theories in information systems – a need for multi-grounding. *Journal of Information Technology Theory and Application* **6(2),** 59–72.

GOTEL O and FINKELSTEIN A (1995) *Contribution structures [Requirements artifacts]* Second IEEE International Symposium on Requirements Engineering (RE'95), IEEE Computer Society.

GREGOR S (2006) The nature of theory in information systems. *MIS Quarterly* **30(3),** 611–642.

GREGOR S and JONES D (2007) The anatomy of a design theory. *Journal of the Association for Information Systems (JAIS)* **8(5),** Article 19.

HEVNER A, MARCH S, PARK J and RAM S (2004) Design science in information systems research. *MIS Quarterly* **28(1),** 75–105.

IIVARI J (1986) Dimensions of information systems design: a framework for a long-range research program. *Information Systems Frontiers* **11(2),** 185–197.

JOU J and SHANTEAU J (1996) An information processing view of framing effects: the role of causal schemas in decision making. *Memory and Cognition* **24(1),** 1–15.

KUECHLER W and VAISHNAVI V (2006) So, talk to me: the effect of explicit goals on the comprehension of business process narratives. *MIS Quarterly* **30(4),** 961–996.

KUECHLER W and VAISHNAVI V (2008) The emergence of design science research in information systems in North America. *Journal of Design Research* **7(1),** 1–16.

Kuechler W, Vaishnavi V and Petter S (2005) The aggregate general design cycle as a perspective on the evolution of computing communities of interest. *Computing Letters* **1(3),** 123–128.
Lethbridge T, Singer J and Forward A (2003) How software engineers use documentation: the state of the practice. *IEEE Software* **20(6),** 35–39.
Lewalter D (2003) Cognitive strategies for learning from static and dynamic visuals. *Learning and Instruction* **13,** 177–189.
Maiden N, Manning S, Jones S and Greenwood J (2005) Generating requirements from systems models using patterns: a case study. *Requirements Engineering* **10,** 276–288.
March S and Smith G (1995) Design and natural science research on information technology. *Decision Support Systems* **15,** 251–266.
Markus L and Lee A (2000) Foreward: special issue on intensive research. *MIS Quarterly* **24(3),** 473–474.
Mayer R and Jackson J (2005) The case for coherence in scientific explanations: quantitative details can hurt qualitative understanding. *Journal of Experimental Psychology: Applied* **11(1),** 13–18.
Merton R (1968) *Social Theory and Social Structure*. Free Press, New York, NY.
Mylopoulos J, Chung L and Nixon B (1992) Representing and using nonfunctional requirements: a process-oriented approach. *IEEE Transactions on Software Engineering* **18(6),** 483–497.
Nelson K, Nadkarni S, Narayanan V and Ghods M (2000) Understanding software operations support expertise: a revealed causal mapping approach. *MIS Quarterly* **24(3),** 475–507.
Nissen HW, Jeusfeld M, Jarke M, Zemanek G and Huber H (1996) Managing multiple requirements perspectives with metamodels. *IEEE Software* **13(2),** 37–48.
Nunamaker J, Chen M and Purdin T (1991) Systems development in information systems research. *Journal of Management Information Systems* **7(3),** 89–106.
Orlikowski W and Iacono C (2001) Desperately seeking the ''IT'' in IT research – a call to theorizing the IT artifact. *Information Systems Research* **12(2),** 121–134.
Parsons J and Cole L (2005) What do the pictures mean? Guuidelines for experimental evaluation of representation fidelity in diagrammatical conceptual modeling techniques. *Data & Knowledge Engineering* **55,** 327–342.
Purao S (2002) Truth or dare: design research in information technology. GSU CIS Department Working Paper, 2002.
Seufert T, Janen I and Bruken R (2007) The impact of intrinsic cognitive load on the effectiveness of graphical help for coherence formation. *Computers in Human Behavior* **23,** 1055–1071.
Simon A (1996) *The Sciences of the Artificial*, 3rd edn, MIT Press, Cambridge, MA.
Stefansen C and Borch S (2008) Using soft constraints to guide users in flexible business process management systems. *International Journal of Business Process Integration and Management* **3(1),** 26–35.
Takeda H, Veerkamp P, Tomiyama T and Yoshikawam H (1990) Modeling design processes. *AI Magazine* **(Winter),** 37–48.
Tversky A and Kahneman D (1981) The framing of decisions and the psychology of choice. *Science* **211,** 453–458.
Vaishnavi V and Kuechler W (2004) Design research in information systems. 20 January 2004, last updated 29 June 2007. [WWW document] http://www.isworld.org/Researchdesign/drisISworld.htm.
Vaishnavi V and Kuechler W (2007) *Design Science Research Methods and Patterns: Innovating Information and Communication Technology*. Auerbach, New York.
Vans A and Von Mayrhauser A (1999) Program understanding behavior during corrective maintenance of large scale software. *International Journal of Human–Computer Studies* **51,** 31–70.
Venable J (2006a) The role of theory and theorizing in design science research. In *Proceedings DESRIST 2006* (Chatterjee S and Hevner A, Eds), Claremont, CA, http://ncl.cgu.edu/designconference/index.htm.
Venable J (2006b) A framework for design science research activities. In *Proceedings of the 2006 Information Resource Management Association Conference* (Khosrow-Pour M, Ed), Washington, DC, 24–26 May 2006, IRMA, Hershey, PA.
Walls J, Widmeyer G and El Sawy O (1992) Building an information system design theory for vigilant EIS. *Information Systems Research* **3(1),** 36–59.
Walls J, Widmeyer G and El Sawy O (2004) Assessing information system design theory in perspective: how useful was our 1992 initial rendition. *Journal of Information Technology Theory and Application* **6(2),** 43–58.
Wand Y and Weber R (2002) Information systems and conceptual modeling – a research agenda. *Information Systems Research* **13(4).**
Yu E (1995) Models for supporting the redesign of organizational work. In *The Proceedings of the Conference on Organizational Computing Systems* (Comstock N and Ellis C, Eds), pp. 225–236, ACM, New York.
Yu E and Mylopoulos J (1994) Understanding ''Why'' in software process modeling. 16th International Conference on Software Engineering, Sorrento, Italy.
Zukier H (1986) The paradigmatic and narrative modes in goal-guided inference. In *Handbook of Motivation and Cognition: Foundations of Social Behavior* (Sorrentino RM and Higgins ET, Eds), Guilford, New York.
Zukier H (1990) Aspects of narrative thinking. In *The Legacy of Solomon Asch: Essays in Cognition and Social Psychology* (Rock I, Ed), pp 195–209, Lawrence Earlbaum and Associates, Hillsdale, NJ.
Zukier H and Pepitone A (1984) Social roles and strategies in prediction: some determinants of the use of base-rate information. *Journal of Personality and Social Psychology* **47(2),** 349–360.

Appendix A

A process change scenario illustrating 'soft context information' (a true story)

Note that this scenario describes the revision of a significant organizational process that involves both information technology and nonautomated process actions. The overall process is sometimes referred to as a 'composite system' (Fickas & Helm, 1992). The mission-critical 'soft context' information for this particular process revision is shown in italics in the scenario description below.

> A medium sized U.S. university made an administrative decision to transition from paper-based student course evaluations to a web-based system. One of the university IT department's senior analysts gathered requirements for the system and was placed in charge of the project. The analyst was told the primary driver for the new system was the high cost of processing the paper forms. The analyst was also cautioned during interviews with several administrators that *the system needed to generate very near the number of evaluations per course that the current system produced or the results would not be accepted*. Not uncommonly this soft context information was never translated into a composite system requirement. A web-based system was developed that, when used, generated exactly the information required by the faculty and administration at a fraction of the cost per response. Unfortunately, the students saw no reason to take on the additional work of entering information into the system at a very busy time in the semester, and the system did not generate enough results to be usable. Several 'obvious' paths to greater use, such as requiring the students to enter evaluation information before grades would be issued for them, are politically unpalatable at the university. After several semesters of unsuccessful attempts to exhort students to greater system use, the university is on the verge of abandoning the system.

Appendix B

See Figures B1–B3.

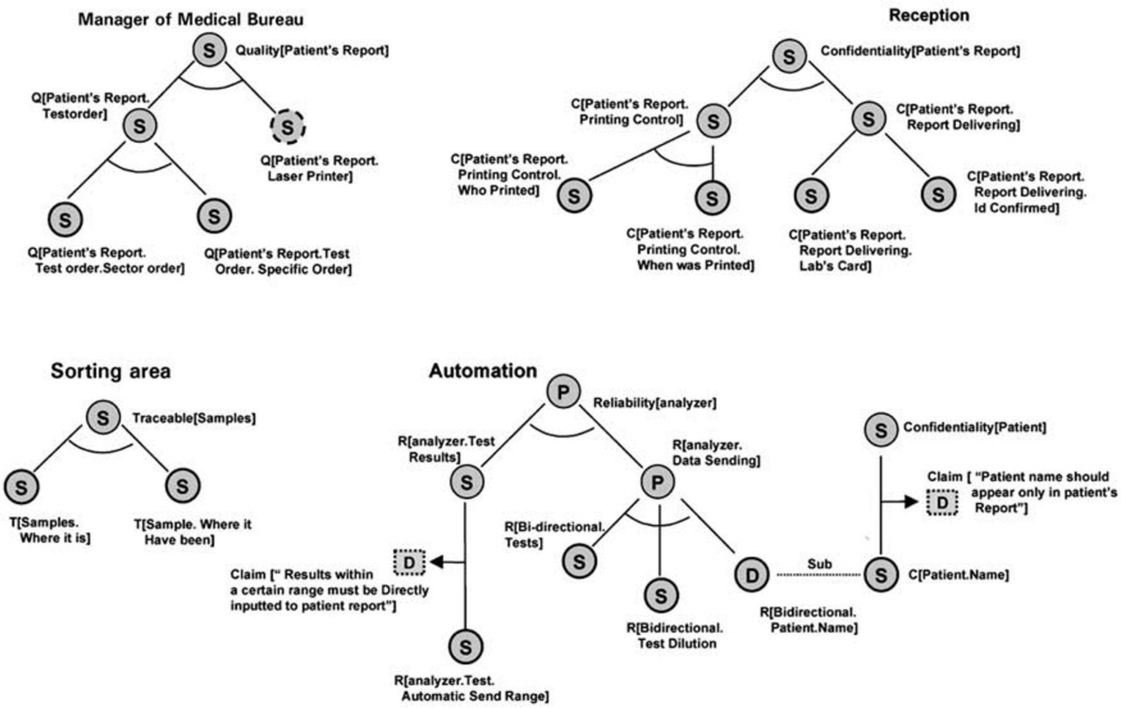


Figure B1 AND/OR graphs used to represent system quality (taken from Cysneiros *et al.*, 2001).

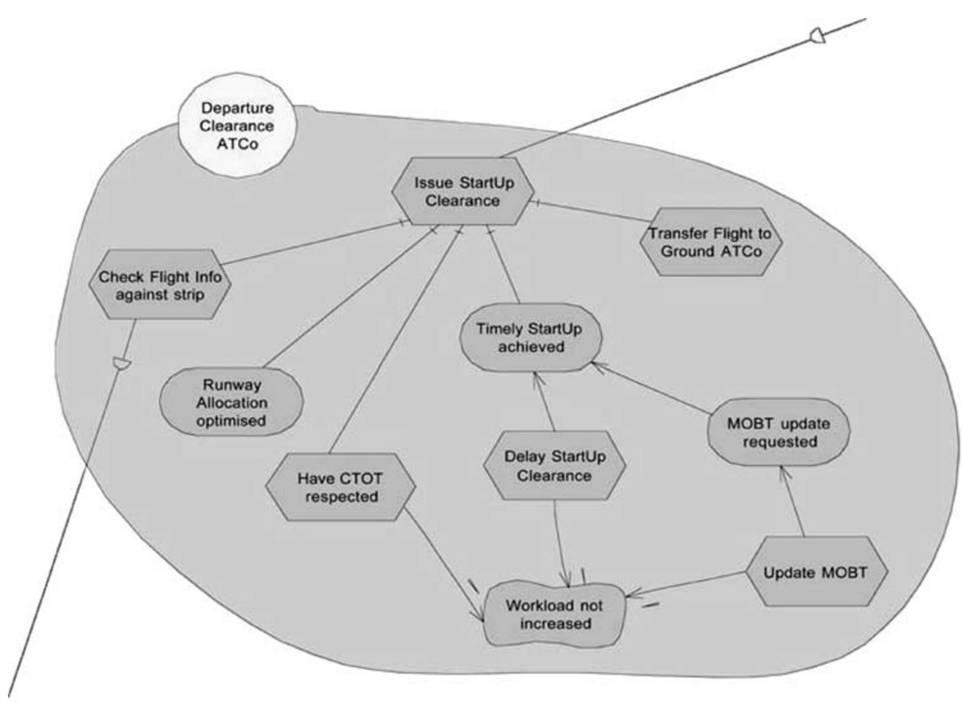


Figure B2 i* graphs used to represent system context for an air traffic control system (a very small portion of the total graph, taken from Maiden *et al.*, 2005).

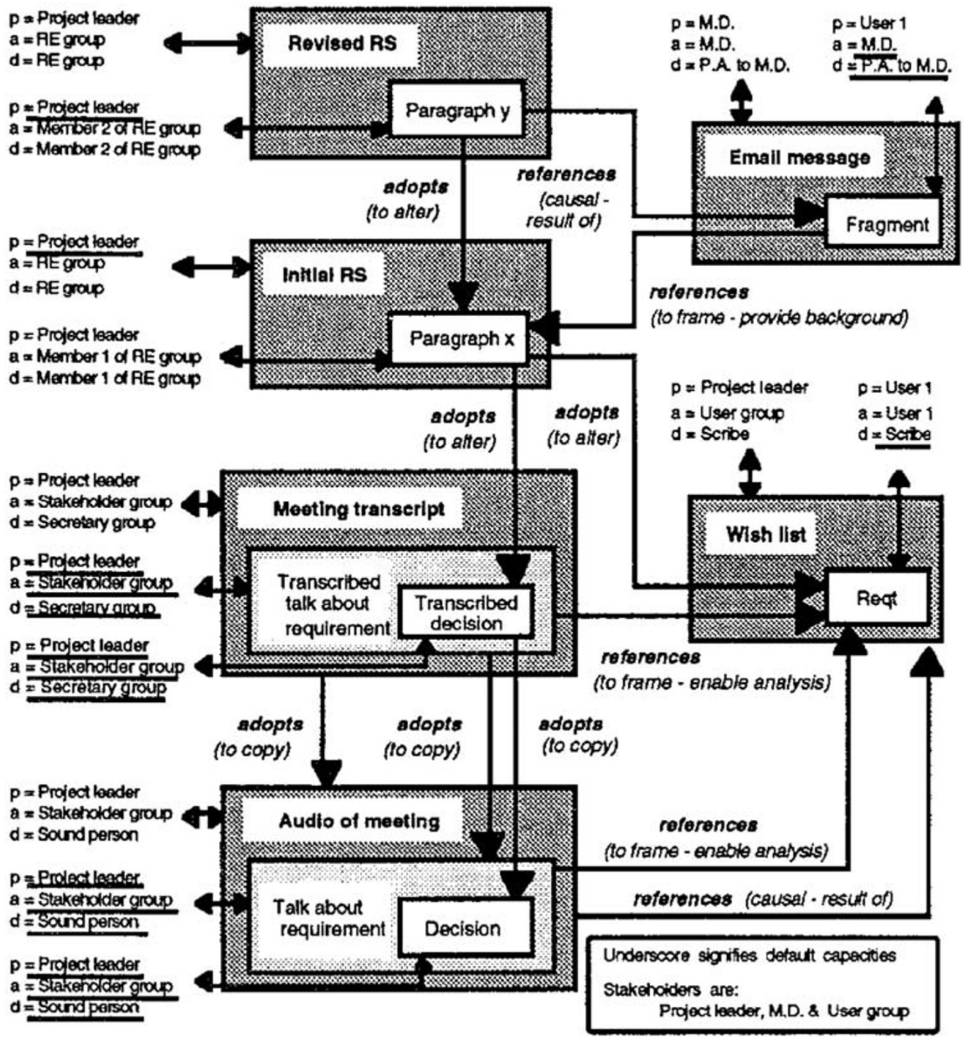
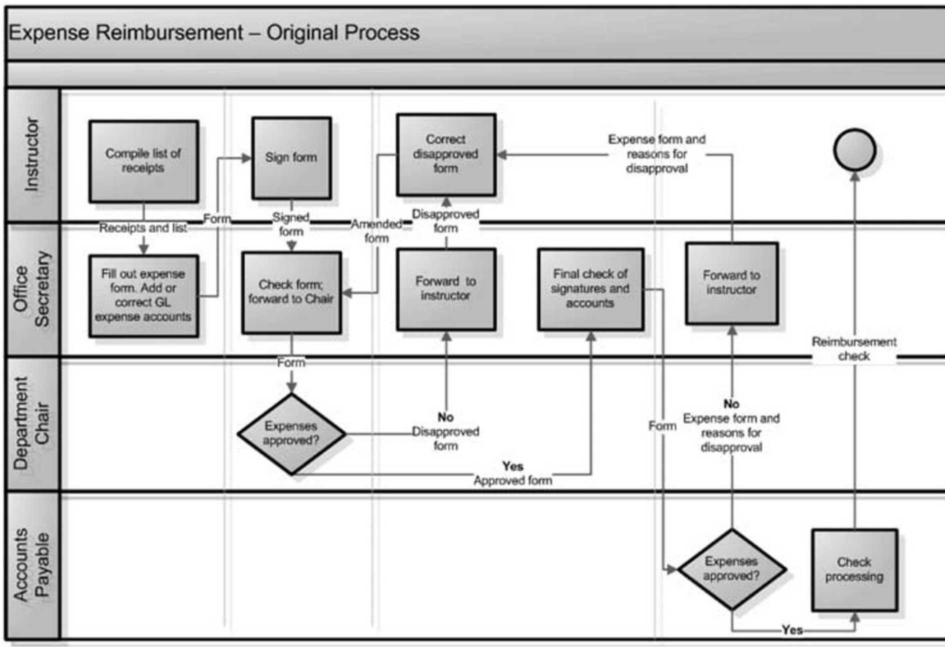


Figure B3 Connectivity structures (taken from Gotel & Finkelstein, 1995).

Appendix C

Sample process graph 'slices' and associated text description and micro-rationale as used in our evaluation prototype



With reference to the diagram above, the prototype works as follows for the *treatment* session:

In the actual prototype, the screen is wide enough to display a 50 character wide text section on the left of the screen and the full diagram on the right of the screen. Initially, instructions are displayed on the left and only slice 0 – the swim lane names and the graphic heading – is visible. The subject must click on the text to view the next information segment. Information segments alternate between narrative – descriptive text and micro-rationales – and the next sequential graphic slice. Text segments are displayed in sequential positions down the text display portion of the screen. Each piece of information, whether text or graphic, fades from view in 9 s. The subject must click on the information to make it reappear for 9 s. The only exception to this is the initial display of the graphic associated with a given text segment. That is, on clicking a text segment, the associated graphic is displayed and both are visible. However, after clicking on the associated graphic slice, both the graphic and its associated text disappear, and the next text segment appears. The prototype records the time and object for every mouse click. During final data analysis the click traces will augment coded transcriptions of the concurrent verbal protocols that were recorded as the subjects proceeded through the process display.