Design Research in the Technology of Information Systems: Truth or Dare

Sandeep Purao
Associate Professor of IST
School of Information Sciences and Technology
The Pennsylvania State University
University Park, State College, PA 16802
and
Associate Professor of Computer Information Systems
College of Business
Georgia State University
Atlanta, GA 30302

Email: sandeep-purao@psu.edu

Under Review
Please contact the author for citation information

Keywords:
IT Artifact, IT Theory, Philosophy of Science, Design Research, Discipline, Research Methodology, Ontology, Epistemology, Semiotics, Hierarchy.

ISRL Categories:
IB01, IB03, AD0102, AH0603, AI0801, AI0802, CB, AI0102, AI0107, AI0116

© Sandeep Purao. 2002. All Rights Reserved.
Design Research in the Technology of Information Systems: Truth or Dare

Abstract

This essay develops the philosophical foundations for design research in the Technology of Information Systems (TIS). Traditional writings on philosophy of science cannot fully describe this mode of research, which dares to intervene and improve to realize alternative futures instead of explaining or interpreting the past to discover truth. Accordingly, in addition to philosophy of science, the essay draws on writings about the act of designing, philosophy of technology and the substantive (IS) discipline. I define design research in TIS as intervention in the representational world defined by the hierarchy of concerns following semiotics. The complementary nature of the representational (internal) and real (external) environments provides the basis to articulate the dual ontological and epistemological bases. Understanding design research in TIS in this manner suggests operational principles in the internal world as the form of knowledge created by design researchers, and artifacts that embody these are seen as situated instantiations of normative theories that affect the external phenomena of interest. Throughout the paper, multiple examples illustrate the arguments. Finally, I position the resulting ‘method’ for design research vis-à-vis existing research methods and argue for its legitimacy as a viable candidate for research in the IS discipline.

Keywords:
IT Artifact, IT Theory, Philosophy of Science, Design Research, Discipline, Research Methodology, Ontology, Epistemology, Semiotics, Hierarchy.

ISRL Categories:
IB01, IB03, AD0102, AH0603, AI0801, AI0802, CB, AJ0102, AJ0107, AI0116
1. Introduction

IS academics recognize the value of studying and teaching the underlying technology of information systems. In spite of this and the rising levels of funding for such research [Colwell 2001], the scientific foundations underlying this critical area of the IS field – design research – have remained largely undeveloped. The visible output of this form of research is virtual artifacts (software and systems) that alter the real world in beneficial (and sometimes, not so beneficial) ways [Blum 1996]. A functional or instrumental view of these outputs does not, however, allow focusing on the technology of information systems per se as it contributes to ‘maintain understanding within the categories of thought which the metaphors that stem from organizational theorizing' provide [Sotto 1997]. Orlikowski and Iacono [2001] recognize this void as they issue a call to ‘deeply engage in the core subject matter, the IT artifact’ mirroring a similar concern almost a decade ago by Walls et al [1992], who articulated the need to develop classes of design theories for IS artifacts. Over the years, in spite of important writings about design research (e.g. March and Smith [1995]), philosophical underpinnings of this form of research have been largely unexplored. Without adequate scientific foundations, research in the technology of information systems (TIS) continues to be a lost child still searching for its scientific home. The present essay addresses this serious issue.

My central thesis is that the goal of the design research paradigm in TIS is not the pursuit of truth as it is articulated for the dominant paradigms in IS. Instead, research in this paradigm dares to invent virtual artifacts that intervene to support and improve real phenomena. Design researchers believe that the proverbial ‘truth’ is not ‘out there’ [Orlikowski and Iacono 2000]. Instead, they facilitate its enactment by creating artifacts. The paper develops philosophical underpinnings of this paradigm for the “technology of information systems (TIS)” drawing on writings in philosophy of science and technology, and design disciplines coupled with those from the IS discipline to:

- articulate the ontological and epistemological stance of design researchers, and
- clarify the outputs of design research to meet the expectations of science.

---

1 The organizational setting continues to remain the setting of choice for IS research [Braa and Vidgen 2001].
I build the argument in several steps. The next section outlines the complex patronage of the IS discipline to establish the need for a distinct paradigm for design research in TIS. Section three briefly describes the design research tradition in TIS and identifies expectations it must meet as a mode of research. Section four proposes the perspective of design research as in(ter)vention in the representation, drawing on semiotics. Building on this perspective, section five develops foundations of the design research paradigm, and articulates the methodology. Section six characterizes the visible and hidden outputs of research in this paradigm. Section seven positions design research in TIS in the constellation of other research modes in the IS discipline, suggesting it as a legitimate mode of research.

2. Relevance

Methodological paradigms are important in science because they legitimize how knowledge may be created and what constitutes valid knowledge. The consequence of such legitimation (or lack of it) for researchers is the impact on rewards, which appear as publications in scholarly outlets, and the choice to practice certain modes of research following implied sanction of the scientific community [Banville and Landry 1989]. Clearly, methodological legitimacy is relevant for academia.

As the IS discipline has evolved, researchers in IS have adopted certain methodological paradigms in search of such legitimacy [Applegate 1996] in the eyes of those who grant tenure. As the study of ‘information systems’ has become part of business schools, it has adopted social science methods, with pockets of influence from engineering and considerable affinity to practice. While these have fueled debates of relevance versus rigor, they have not provided sufficient guidelines to actualizing the practice of design research. Figure 1, adapted from Applegate [1996] shows this complex patronage structure for the IS discipline, with roots in social and natural sciences, respect for the supervisory structure from the management disciplines, and an affinity to engineering and IS practice.
This complexity has meant that researchers in IS are expected to work at the nexus of several expectations that can be at odds with one another. This is particularly true for researchers engaged in design research on TIS (who are largely driven by the affinity relationships). The notion of (borrowed) research methods (answerable to one set of demands) originally seen as liberating or legitimating has, thus, become a trap for this sub-group of researchers. Expectations codified in research methods from the dominant research paradigms in IS have failed to provide sufficient guidelines to this group.

Writing against such legislation of method, Feyerabend [1993, p. 14] argues that “the idea of a method that contains firm, unchanging ... principles for conducting the business of science meets considerable difficulty when confronted with the results of historical research.” A radical interpretation of his views means ‘anything goes’ in the pursuit of science [Feyerabend 1993, p. 19]. A more moderate reading leads to the sensible conclusion that methods must evolve, and that they should be a matter internal to a discipline, at least to some extent. They should not be dictated by the whole scientific community but should be communicated to the scientific community at large. This is especially true for design researchers in the IS discipline, who engage in the design of virtual artifacts intended to create new realities – something the traditional philosophy of science could not have anticipated. Dictates from philosophy of science must, therefore, be adapted to these new demands. In spite of such lack of accepted ‘method,’ design research tradition in IS has continued to thrive.
3. **Tradition**

A research tradition is a macro construct that represents a cluster of beliefs, that is, fundamental views about the world that specific theories exemplify [Laudan 1996, p. 83]. In this sense, design research in TIS constitutes such a tradition. Origins of this tradition can be traced to Simon’s writings on *Sciences of the Artificial* [Simon 1970]. It continues to thrive as sub-communities and sub-groups [Constant 1984] working on ongoing concerns such as software engineering and emerging ones such as mobile commerce. This is evident in communities such as the Workshop on Information Technologies and Systems, thriving doctoral programs in IS departments such as University of Arizona and University of Texas-Austin, and research centers focusing on areas such as Electronic Commerce. Researchers in this tradition design artifacts that are intended to control or transform reality, social or natural [Bunge 1984]. The research requires looking-ahead to new possibilities, not only looking-back to understand or interpret the past. IT artifacts\(^3\) are not natural, neutral, universal or given. Instead, they are designed, that is, shaped by the interests, values and assumptions of researchers, prospective users and developers [Orlikowski and Iacono 2001]. The design\(^4\) researchers, therefore, purposefully mould IT capabilities to shape phenomena in the real world in accordance with a set of values. Figure 2 outlines key elements of this mode of research.

```
- Design, from the Latin *designare*, which means to point the way,
- Invention, that is, not discovery or replication,
- Teleological Stance, that is, purposeful advancement, ensuring relevance,
- Axiological Perspective, that is, value-orientation, and
- Pragmatic Attitude, that is, a focus on making it work, requiring rigor.
```

**Figure 2. Key Elements of Design Research**

Design situations start with a need and require intention. Writings on philosophy of technology suggest several design situations that yield research questions for the design researcher. Figure 3 classifies these to follow the categories of practice-generated and discipline-generated research questions.

---

\(^2\) Naur [1992] echoes a similar concern as he concludes that it is a mistake to provide a set of guidelines for *design* [italics introduced].

\(^3\) Artifacts may take several ‘forms.’ These are described in a later section as outputs of design research.

\(^4\) Dilnot [1980] suggests three meanings of design – the act of designing, the designed artifact, and the values or aesthetics embedded in the artifact. Blum [1996] suggests that for information systems (particularly, software), the design is self-realizing, that is, the design is the artifact and the artifact is the design.
These categories can be adapted for research in TIS. For example, ‘presumptive anomalies’ represent situations where the researcher argues that current technology will fail in expectation of new demands from practice. An instance of this can be seen in TIS for research related to object-relational databases, which are motivated by recognition of situations that cannot be supported by relational databases [Stonebraker 1997]. Similar examples can be considered for the other categories.

Given the above focus, the most visible output of the design research tradition is the artifacts, unlike the conventional research traditions, whose visible output is theories, facts, laws and assertions. Researchers in this tradition use the craft they have learned as apprentices, following methods of their senior peers, often without questioning and sometimes not even knowing the underlying assumptions [Reich 1995]. The research assumptions, thus, become part of the implicit unarticulated research culture, a situation comparable to the craft stage [Gibbs 1994]. Few researchers in the IS discipline have acknowledged the need to articulate these implicit assumptions underlying design research [Probert 1997]. To claim legitimacy, the design research tradition must identify its underlying beliefs and assumptions including, first, clarification of the nature of knowledge it creates in terms such as theory-building or theory-testing; and second, articulation of fundamental world-views such as the ontological and epistemological stance.

Theory building involves construction of an abstract conceptual scheme that provides a metaphorical re-description of a phenomenon by means of symbolic construction [Abraham 1982]. Formulation of a theory gives rise to claims and propositions, which then must be tested. Unless we assert that theory plays no

---

5 Reich [1995] suggests two possible reasons for this lack of articulation: indifference, which leads to a failure in communicating with novice researchers; and ignorance, which leads to a failure in communicating with other traditions/disciplines.

role in design research, it is imperative that the role of these phases is clarified for design research. In
particular, we need to demonstrate that design research does not involve merely atheoretical tinkering, and
market acceptance of its outputs. Figure 4 summarizes these challenges.

<table>
<thead>
<tr>
<th>Conventional Research Paradigms</th>
<th>Design Research in Technology of IS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Theory-Building</strong></td>
<td><strong>Theory-Building</strong></td>
</tr>
<tr>
<td>• Create a metaphorical re-description of a phenomenon by means of symbolic construction</td>
<td>• Demonstrate that designing an artifact does not involve merely atheoretical tinkering</td>
</tr>
<tr>
<td><strong>Theory-Testing</strong></td>
<td><strong>Theory-Testing</strong></td>
</tr>
<tr>
<td>• Test claims and propositions from the theory - gather evidence, from observations, for or against claims or propositions of the theory</td>
<td>• Clarify that testing does not merely consist of market acceptance of the artifact?</td>
</tr>
</tbody>
</table>

**Figure 4. Challenges for the Design Research Tradition in TIS - Set I**

Second, fundamental world-views are expressed in terms of ontology and epistemology. The former refers to assumptions about the phenomenon under investigation; the latter refers to ways of knowing this phenomenon. The former drives the latter and in turn, is explicated into a methodology. The design research tradition lacks a clear articulation of these world-views. On the other hand, the two dominant research traditions, positivist and interpretive, can be described in terms of such world-views. Unless corresponding positions can be succinctly articulated, the design research paradigm in the technology of IS cannot claim to be a legitimate candidate. These represent the second set of challenges the design research tradition in TIS must meet, summarized in Figure 5.

<table>
<thead>
<tr>
<th>The Positivist Research Paradigm</th>
<th>Design Research in Technology of IS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• <strong>Ontology</strong>: realist</td>
<td>• <strong>Ontology</strong>: Clarify what ontology would mean for researcher creating artifacts</td>
</tr>
<tr>
<td>• <strong>Epistemology</strong>: dualist, objective</td>
<td>• <strong>Epistemology</strong>: Derive the epistemology from this ontological stance</td>
</tr>
<tr>
<td>• <strong>Methodology</strong>: no confounding influences</td>
<td>• <strong>Methodology</strong>: Specify the implications of the above for the methodology</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>The Interpretive Research Paradigm</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• <strong>Ontology</strong>: relativist</td>
<td></td>
</tr>
<tr>
<td>• <strong>Epistemology</strong>: monistic, subjective</td>
<td></td>
</tr>
<tr>
<td>• <strong>Methodology</strong>: hermeneutic, dialectic</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 5. Challenges for the Design Research Tradition in TIS - Set II**
Table 1 shows exemplars\(^7\) that illustrate research questions addressed by design researchers, classifying them following the scheme in figure 3 above. The table also illustrates the lack of explicit articulation of a research methodology with the help of direct quotes from the papers.

Without clear answers to the above challenges, that is, without the benefit of a well-articulated research paradigm, the design research tradition in the IS has suffered from the stigma of being considered ‘technology, as mere application of the outputs of pure science’ [Bush 1945], consulting and following the lure of design and construction [Weber 1997, p. 18]. The few writings in the design research tradition have proposed terms such as systems development research [Nunamaker et al. 1991], design theories [Walls \textit{et al.} 1992], design science [March and Smith 1995], AI investigations [Baldwin and Yadav 1995] or software engineering research [Gregg \textit{et al.} 2001]. While many of these have provided useful pointers, none, with the exception of Gregg \textit{et al.} [2001], have attempted to address the underlying world-views or articulated the philosophical underpinnings. Morrison and George [1995] aptly illustrate, in statistical terms, difficulties faced by design researchers in TIS, which the lack of a well-articulated method contributes to. Unless the above challenges are met, design research in TIS will remain subjected to and unable to meet methodological mandates from competing research paradigms IS or supervisory disciplines.

4. **In(ter)vention**

To lay out answers to these challenges, I begin with a key element of design research – invention. For design research in TIS, this involves in(ter)vention in a specific mode of representing the world [Sotto 1997], one of “inscription mediated through a numerical mode of representing” [Bolter 1991]. The design researcher intervenes, that is, manipulates the representation to simulate action in the world of signs. This world of signs captures the internal representations (as opposed to surface representations). A surface representation may be pencil or ink marks on paper. On the other hand, internal representation includes symbols maintained internally within a device. The device transforms the internal representation into some surface representation that can be interpreted and used by an external agent [Norman 1991]. This understanding is at core of

\(^7\) The tables containing exemplars are placed at the end of the paper to avoid hindering the flow of the paper.
Simon’s physical-symbol system hypothesis, which states that a physical-symbol system has the necessary and sufficient means for general intelligent action [Simon 1970].

This perspective is potent, but not sufficiently rich for classifying and understanding the variety of situations a design researcher may engage in. For instance, optimum placement of transceivers for mobile cellular traffic, workflow automation or natural language processing to simulate artificial intelligence all represent viable examples of design research situations in TIS that demonstrate the inherent complexity and different levels of concerns design researchers face. While intervention in the world of signs may still be seen as the core of this research activity, another important aspect is necessary to understand this complexity. To capture this notion of complexity, I turn to the notion of hierarchy.

Hierarchy refers to a structure made up of levels. Bertalanffy [1973], and more recently by Kline [1995] describe hierarchy in terms of concerns addressed by disciplines at different levels (e.g. physics, economics). Kline [1995] suggests that interactions across levels may be understood in terms of Polanyi’s principles [Polanyi 1968], which assert that (a) levels mutually constrain, but do not determine each other, and (b) the upper levels harness the lower levels to carry out desired behaviors. The first principle, known as interfaces of mutual constraints, indicates that concepts of the lower level cannot be simply aggregated to obtain those at the next higher level nor can concepts at the higher level be disaggregated to derive concepts at the lower levels. An analogy is seen in the distinction between problems of data storage and semantic database design. Results from design research cannot be simply aggregated or dis-aggregated across these levels. The second principle, known as levels of control, indicates that operations at a level cannot violate the governing principles at lower levels. Instead, they exploit the lower levels towards a purpose, which the lower levels, left to themselves, would not seek. This principle suggests the importance of external agency, that is, degrees of freedom that an external agent (the design researcher) must exercise. Together, the two principles reject the reductionist as well as synoptic views. The levels mutually constrain but do not determine each other (first principle), and the upper levels harness the lower levels to carry out the desired behaviors (second principle).

Following Lee and Baskerville [2001], we consider these as data.

---

8 The synoptic view argues that the higher level exist independently of the lower levels, whereas the reductionist view argues for the ability to derive the higher levels from the lower levels.
The idea of hierarchy and the accompanying principles suggests a plausible perspective for understanding design research as in(ter)vention in one or more of these levels. An intervention may change how one level harnesses the capabilities of the levels below or changes the capabilities at one level to affect potentialities at the levels above.

The notion of levels should, however, be made more specific, building on the foundation of representation and manipulation of signs. Semiotics, the study of representation, interpretation and manipulation of signs suggests a suitable framework for this purpose. Classical semiotics [Peirce 1931-1935] describes three levels: syntactic, semantic and pragmatics. More recently, Stamper [1996] has suggested additional levels below and above these to address the dimensions of cost and value. These levels can be viewed as a superstructure building on the fundamental symbol-world hypothesis. Figure 6 outlines these levels.

**Figure 6. The Levels of Semiotics [adapted from Stamper 1996]**

The lowest level deals with the creation of tokens or symbols to represent the physical world where concerns in terms of energy or other resources, are important. The empirics level deals with statistical properties of these tokens that result from token variety. The next level, syntactics, is concerned with structures of tokens. The fourth level deals with semantics, that is, meanings assigned to tokens to represent
reality. The fifth deals with pragmatics, that is, the interpretation and use of meanings such as adding intentionality to utterances. Finally, the social world represents the value of information exchanges, where the effects are seen in terms such as expectations, contracts and commitments [Stamper 1996]. Stamper argues that these levels provide the complete range of possibilities for research in IS. These levels correspond to different contexts suggested by Lyytinen [1987] for generation of object systems as part of system development approaches. The lowest two levels correspond to the technology context, the next three correspond to the language context, and the final level corresponds to the organizational context. Lyytinen, like Stamper, argues that these provide an exhaustive hierarchical perspective.

Semiotics provides a well-defined perspective to instantiate the notions of hierarchy and intervention to understand design research in TIS. Design research in TIS, thus, involves (a) changing how one level (e.g. pragmatics) harnesses the capabilities of (that level or) the levels below (e.g. semantics), or (b) changing the capabilities at one level (e.g. syntactics) to affect the potentialities at (that level or) the levels above (e.g. semantics). Polanyi’s principles suggest the degrees of freedom available to the design researcher and the constraints s/he faces. Figure 7 shows this notion of intervention where the design researcher must respect constraints from the lower levels, while trying to realize goals or improving potentialities at higher levels.

**Figure 7. Design Research as In(ter)vention in a Semiotic Level**

At the lowest semiotic level, the design researcher faces constraints from the physical world, and the conversion of energy to information. At the highest level, the design researcher has infinite degrees of freedom and is free to shape the values. These two extreme cases are indicative of the increasing influence of
the natural/physical sciences at the lower semiotic levels, and of the social/behavioral sciences at the higher semiotic levels. Focusing on semiotics as the key framework allows us to instantiate the notion of hierarchy for TIS - to explore the ‘essence’ of IT, not its use [Sotto 1997] to deeply engage in the core subject matter, the IT artifact [Orlikowski and Iacono 2001], and takes into account the importance of representation of the real into the virtual [Sotto 1990, Zuboff 1988].

Table 2 (at the end of the paper) shows exemplars of design research in TIS, which can be understood in terms of intervention at different semiotic levels. With the help of the above foundation, I move next to the challenges identified earlier (Figures 4 and 5). The first set of challenges involves articulation of the design research paradigm.

5. **Paradigm**

Based upon the discussion thus far, two key elements emerge. First, as the use of semiotics suggests, design researchers in TIS virtualize and manipulate signs and symbols that correspond to phenomena in the real world. An analogy for this is found in the notion of “doubling” as used by Foucault [1970]. Information technology can be viewed as doubling the formalized representations of human agency (much like the doubling of the knowledge of human nature explicated by Foucault). Sotto [1997] suggests that this doubling is contained in the notion of virtuality used by the producers and consumers of IT to characterize a new space, referred to as cyberspace or electronic space⁹. Second, design research in TIS differs from a social science perspective on IS research in that it does more than reflect upon and interact with an ontologically static and unchanging world [Probert 1997]. Due to its intervention in the virtual, design research influences and thereby changes reality over time. A direct consequence of these two elements is the realization of the invention (often, in the form of an artifact) as coming into being at the intersection between the inner and the outer environment [Simon 1970]. At the meeting point between representation and phenomenon, at the point where technology and human agency interact, we can recognize the primary, irrefutable and enigmatic existence of the artifact (invention). The outer environment represents the phenomenon of interest, where
the artifact, once created, will be exercised. The inner environment represents the internal virtual environment of the artifact where aspects of the phenomenon of interest are represented and manipulated. A black-box, functionalist or ‘as-use’ view of TIS negates this essential double, which an opening of the black-box can provide. These observations drive articulation of ontology and epistemology for design research in TIS.

5.1 Ontology

The ontological stance for the design researcher in TIS can be described as *evolutionary* and *complementary*. It is evolutionary because it represents shifting ontological assumptions and complementary because of the dual considerations of the phenomenon and the artifact. Its evolutionary nature – over the research cycle – is comparable to Latour’s notion of ‘variable ontology’ [Latour 1992, p. 144]. The initial stance of the design researcher about the *phenomenon* of interest may be described as *moderated realist*. The design researcher is concerned with a simplified understanding of the phenomenon of interest, not necessarily the whole, complex truth about the phenomenon since s/ he will begin to shape it anyway during the research cycle. S/ he considers a simplified version of the phenomenon, as the research cycle begins. On the other hand, the researcher’s initial stance about the *artifact* that is yet to be built is *emergent* because the artifact exists only in the mind of the design researcher. While the design research community may share [Konda 1992] some notion of what is desirable or possible, the path the design researcher will choose is likely to be unique to her/ his values and expressed goals.

As the research cycle progresses, these ontological stances shift. The *artifact* begins to take shape and gradually becomes a thing in the world; that is, it begins to be perceived with a *realist* stance. The unforgiving and complex environment (computing or formal) in which it is being created can contribute to this shift in the ontological stance. The ‘virtual reality’ being created by the design researcher begins to acquire a distinct ontological status (e.g. Pruitt and Barett [1991] describe the corporate virtual space that must be ‘entered’ (quoted from [Sotto 1997]). Benedikt [1991] suggests a similar perspective as he argues that the ontological

---

9 Corresponding terms such as virtual reality, virtual space, digital organization, virtual worlds, avatars, and electronic
status of representations (embodied in the artifact) exists in a space ‘borrowed from but not identical with’ the phenomenon. The notion of a distinct ontic status corresponds to the larger ‘world of objects’ that makes representation and manipulation possible [Newell and Simon 1976, p. 110]. On the other hand, the phenomenon of interest ceases to be a thing in the world unaffected by the researcher’s efforts. Instead, it becomes imbued with characteristics of the artifact that is being built. The design researcher moulds the phenomenon; that is, a changed version of the phenomenon begins to assume an emergent ontological stance complementing the realist stance of the artifact. Lyytinen [1987] suggests different choices (along the axes of determinism-voluntarism and individual-collective) that provide possible frames that the design researcher uses to reflect upon the phenomenon. Figure 8 captures this shifting ontological stance. It shows that the artifact progresses from an idea to a ‘thing in the world,’ as the phenomenon it is intended to support becomes more densely interpreted in relation to the artifact. The progression may not be smooth as depicted but may have several moves back and forth between the two extremes in a pragmatic manner as the design researcher moves along the research cycle.

Figure 8. An Evolutionary and Complementary Ontological Stance


13
encourages thinking about the progression from thought, abstract objects and empirical objects in a manner that resonates with the above derivation. Gregg et al [2001] allude to an ontology of multiple realities for software engineering research that lends further support to the above. Modes of problem identification (e.g. perceived from the environment) recognized in writings on philosophy of technology (see figure 3) also lend support to this view [Laudan 1984a]. As researchers initiate projects, they often cite evidence to support existence of ‘the problem,’ that is, according the phenomenon a realist ontology. On the other hand, calls to validate technology in academic journals [Tichy 1998] suggest that towards the end of the research cycle (e.g. during the publication process), a realist ontology is accorded to artifacts created through the research cycle. Lyytinen [1987] outlines several competing ontological positions for object system generation in IS development approaches. These range from realism to nominalism\(^\text{10}\) depending upon the context selected. Both accord a distinct ontological status to the realization of the TIS into an artifact. The evolutionary and complementary stance outlined above, thus, finds strong support from several quarters.

5.2 Epistemology

The epistemological process for research in TIS may be characterized as knowing through making, unlike the dominant IS paradigms, which engage in knowing through observing or participating [Guba and Lincoln 1989]. This difference is dictated by the goals of the traditional modes, which involve ‘truth-seeking’ with the goal of discovery and understanding, as opposed to those for design research, which involve ‘daring’ to imagine future worlds. The epistemological stance of the design researcher can, therefore, be described as reflective and hermeneutic.

It is reflective [Schön 1983] because the design researcher shifts between and pushes against the dual realms of the phenomenon and the artifact. Both correspond to Popper’s first world [Popper 1968a]. The design researcher generates data and theory (Popper’s second and third worlds) using a highly selective conjecture/analysis approach [Simon 1970]. The conjecture/analysis cycles in designing have been long

\(^{10}\) Realism ascribes existence to phenomena independent of thought, that is, as non-mental in character. Nominalism refers to the view that only individual objects exist, and does not allow references to abstract objects such as properties, classes and modalities [Boyd et al 1991].
recognized [Hillier 1976]. Darke [1979] proposes a similar notion, called ‘primary generators.’ Both views aim at variety reduction, i.e. reducing the possible multiple worlds that the design researcher must consider. The researcher adopts a hermeneutic stance as s/he attempts to arrive at knowledge - the fit of data and theory to the real world. The conjecture/analysis cycles, thus, involve the gradual bridging of the gap between need and artifact [McPhee 1997, p. 21]. Bunge [1984] suggests a mixture of critical realism and pragmatism, varying the ingredients as needed, to maximize efficiency of the design process regardless of philosophical loyalties, which resonates with an action-oriented view [Winograd and Flores 1984]. Such ‘epistemological chaos’ alluded to by some researchers [Cross et al 1980] can be better understood with the proposed hermeneutic and reflective stance.

The stance does not, however, require the design researcher to deal with an unyielding ontology. Instead, design of the artifact and interpretation of the phenomenon proceed in tandem. The hermeneutical view involves two kinds of dialogical exchanges, one, between the researcher and the idea of the artifact, and the other, between the researcher and the perception of the phenomenon. This allows the ‘ends’ to remain undefined and fluid, avoiding blindness [Heidegger 1962]. The design researcher arrives at an interpretation (understanding) of the phenomenon and the design of the artifact simultaneously. Creation of the artifact and creation plus understanding of a correct idea of the artifact, therefore, become part of the same epistemological process and cannot be separated [Feyerabend 1993, p. 17]. For complex design situations, the final goal often remains unknown until it is reached [Rittel and Weber 1984]. This ‘knowing through making’ makes the epistemology of design research unstable, making prescriptive accounts problematic. Instead, as described here, an understanding of the dual nature of the stance along with the progression towards congruence allows a minimal specification of this stance. Figure 9 summarizes this epistemological stance.
The design research cycle progresses through to creation of the artifact, according it an objective status, and in the process, interpreting the phenomenon\textsuperscript{11}. The derivation is supported by the ontological stance outlined earlier, as well as other writings. Gregg et al. [2001] allude to an objective/interactive epistemology for software engineering research that lends support to my formulation. Baldwin and Yadav [1995] also suggest an alternative similar to ours. Their other alternative, hypothetical-deductive, can, in fact, be understood as a hermeneutical-reflective stance that takes place at the conceptual level, followed by creation of a situated artifact, similar to that followed for artificial intelligence research (e.g. [Lenat and Brown 1984]). Lyytinen [1987] suggests positivism as the dominant epistemological stance for object systems generated in the context of IS development, supporting the notion of reaching an objective status for the artifact being designed (figure 8). By creating a new artifact, the researcher sets the stage for new conversations, connections and communications [Winograd and Flores 1984].

These two central concerns, ontology and epistemology, as explicated above, spell out the hitherto unarticulated cluster of beliefs subscribed to by design researchers in TIS – which drives articulation of an idealized methodology.

\textsuperscript{11} Once created, the options of a positivist or interpretive stance are open for studying the artifact. For example, the artifact may be studied in the context of its use, that is, using an interpretive lens [Orlikowski 1992] or may be considered as an antecedent of firm performance, that is, using a positivist lens [Mukhopadhyay et al. 1995]. Figure 9 shows these options as dotted lines to the right.
5.3 Methodology

The methodology for design research may be characterized as a creative process that involves generation of new thoughts [Willem 1990] and imaginative jumps to future possibilities. While this aspect is important [Koestler 1964, Csikszentmihalyi 1996], I focus, instead, on delineating an idealized process for the design research methodology with a view to demonstrating how it draws on the discussion above, and clarifying its inputs, including its use of the semiotic levels. Following the epistemological stance, the methodology for design research can be characterized as a hermeneutic process that explicitly considers the inner and the outer environments of the artifact. The design researcher enters the hermeneutic circle with an idea of an anticipated meaning of a yet-to-be-created artifact.

Specifically, framing of the phenomenon is informed by higher semiotic levels, making knowledge of principles underlying cognitive science, organizational behavior and management practices a key input to the process\textsuperscript{12}. Advent of new industry practices (e.g. supply chain management) and attendant emerging theories can also form the basis of this framing. Given the innovative nature of the design research process, the theory base can be often incomplete. This framing, based on implicit and often incomplete theories suggests the potential that the design researcher strives for. The discovery, scoping and articulation of this potential goal itself require a hermeneutic process that takes into account known theories.

A corresponding process is seen at the lower semiotic levels, which dictate feasibility of the invention. This requires a substantive understanding of appropriate technologies (e.g. telecommunications, software engineering), along with deep knowledge of prior design research, which can also suggest promising directions and warn of blind alleys. These iterations allow the design researcher to identify parts and sub-parts [Baldwin and Clark 2000], some of which may be solved with existing research, and others that require innovative solutions. The design researcher attempts to create and arrange these components to realize the intended behavior suggested by the first hermeneutic cycle.

The two sub-processes outlined above become part of the larger hermeneutic circle supported by symbol manipulation techniques at different semiotic levels such as modeling, optimization (e.g. linear

\textsuperscript{12} unlike the vision of early technologists as tinkerers [Bell 1999].
programming or queuing), simulation (e.g. continuous or discrete event), natural language processing, knowledge representation, automatic reasoning and others. These techniques [Notations 2001] represent tools of the trade for the design researcher comparable to the statistical techniques used by social scientists. The iterations are guided (and facilitated) by constraints, external and internal [Lawson 1980] as the process moves forward as a series of decisions determined by the current representations, understanding of the phenomenon and the researcher’s values. The evolution of the design results in a convergence of goals, constraints, and anticipated impact of the artifact on the phenomenon. Recognizing that there are no fundamental truths in design, the possibility exists that other designs may exist that satisfy the constraints better\(^\text{13}\). Satisficing [Simon 1970], therefore, plays a large role in the researcher’s decision-making process. The hermeneutic process is, however, tempered. The multiplicity that a hermeneutic vision allows is often easily conflated with infinity, settling for indeterminate subjectivity. I concur, instead, with Carroll and Kellogg [1989], who suggest that the process is bounded by theories that contribute to framing of the phenomenon and prior design research that suggests new possibilities for designing the artifact. Figure 10 captures an idealized version of this process.

\textbf{Figure 10. An Idealized Methodology for Design Research in TIS}

In practice, the process is often opportunistic with conscious and subconscious manipulation of available knowledge and representations in a manner that is best described as ‘play\(^\text{14}\).’ The ‘play’ element

\(^{13}\)We discuss evaluation of design research later, in section 7.

\(^{14}\) “It is often taken for granted that a clear and distinct understanding of new ideas proceeds or should precede their formulation or expression. Yet, this is not the way children develop. They use words, combine them and play with them,
allows the design researcher to interact with the representations and facilitates the conjecture/analysis cycles. The iterations (in the sub-processes and the macro process) allow the design researcher to operationalize a reflective and hermeneutic epistemology following the evolutionary and complementary ontological stance.

**Table 3** (at the end of the paper) illustrates the characterizations of the phenomenon under investigation and the artifact being designed at *early* and *late* stages of design research following the dual ontological assumptions. Quotes from these articles suggest that early vs. late characterization of the two follow the evolution suggested above. This articulation suggests answers to the first set of challenges (Figure 4). The second set of challenges (Figure 5) requires a deeper investigation of the outputs of design research.

### 6. Outputs

It is often argued [McPhee 1997, p. 22] that the output of design (i.e. artifacts) comes to exist in a manner different from the more abstract output of research (i.e. knowledge and theories). A more enlightened view is, therefore, necessary to understand that design research produces more than just artifacts. The situated implementation of an invention (artifact) as software or system may, in fact, remain the most visible output of design research [Blum 1996]. It serves to realize the structure of the artifact to ensure that the design is feasible. It is, however, the least important. At least two other kinds of outputs are more important for design research. The first represents operational principles (reproducible knowledge) that the artifact illustrates. It represents a symbolic, manipulable representation of concepts and abstractions in the form of operational principles. It ensures that the intended behavior of the artifact is explicated in accepted forms. The second requires that I distinguish between the operational principles and a metaphorical understanding of how the artifact supports or controls the phenomenon of interest (emergent theory). It ensures that the expected behavior of the phenomenon, in conjunction with the artifact, is articulated. These three forms may be loosely mapped\(^{15}\) to the terms developmental, formal and conceptual suggested by Gregg et al [2001]. Figure 11 outlines these three outputs.

\[^{15}\text{Broadly distinguished as object, process and knowledge by Mitcham [1978].}\]

---

until they grasp a meaning that has so far been beyond their reach. And the initial playful activity is an essential prerequisite of the final act of understanding” [Feyerabend 1993, p.17].

**Figure 11. The Outputs of Design Research**

The thick oval at the bottom indicates the most visible output, the artifact, the thin oval in the middle indicates the knowledge generated as operational principles, and the dotted oval indicates the emergent theory instantiated in the artifact. Not all design research may produce all three forms. The contributions of a specific design research project may, then, be characterized in the above terms. Figure 12 shows these outputs along two dimensions. The first dimension represents the domain of the phenomenon (i.e. the semiotic level(s)), and the second represents the contribution of design research, along the three layers described above. The entries in cells show classifications of the outputs of design research in TIS. Typically, a specific research project would occupy one or more contiguous cells in this table. The two dimensions, then, suggest ways to identify research forms for design research. I elaborate on the contributions of ‘knowledge’ and ‘theory’ in the next two sub-sections.

<table>
<thead>
<tr>
<th>Contribution of Design Research</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Theory</strong></td>
</tr>
<tr>
<td>Social</td>
</tr>
<tr>
<td>Pragmatics</td>
</tr>
<tr>
<td>Semantics</td>
</tr>
<tr>
<td>Syntactic</td>
</tr>
<tr>
<td>Empirics</td>
</tr>
<tr>
<td>Physical</td>
</tr>
</tbody>
</table>

Examples cited from:

**Figure 12. Characterizing Design Research Forms**
6.1 Knowledge

The middle oval (figure 11) represents operational principles, that is, the knowledge created by design researchers. Following Dasgupta (1996), I define an operational principle as “any technique or frame of reference about a class of artifacts or its characteristics that facilitates creation, manipulation and modification of artifactual forms.” An operational principle, therefore, specifies ways of doing things in a reproducible manner (Laudan 1984). This codification of operational principles challenges the traditional ‘dual knowledge thesis,’ in that it attempts to operationalize the peculiar modes of ‘design knowledge.’ This operationalization resonates with the accepted practice of promulgating normative models that guide professional knowledge. These normative models may include a descriptive component but the intention is to prescribe a desired approach to addressing a class of design situations. We may instantiate this as, say, a proposal to think about groupwork support tools in a particular manner, or rules and procedures for the creation of such tools. Robey (1996), for example, suggests ‘configuration of useful business applications ...’ and ‘knowledge about the development of IS applications’ as valid examples of knowledge produced by IS research. Simon’s notion (1970) of procedural rationality also resonates with the idea of operational principles. In according operational principles the status of knowledge, I break ranks with semi-official ideologies that place the science-technology relationship as producer and consumer of knowledge (Bush 1945). The operational principles may themselves be viewed as theory about the workings of the inner world of the artifact, following Newell and Simon’s (1976) characterization of computer science as empirical enquiry. Several aspects of computer science refer to these as theories (e.g. database theory). Similar characterizations of operational principles as theory are found in Lenat (1982) and Baldwin and Yadav (1995). I retain use of the term ‘knowledge’ to distinguish operational principles from the next layer (discussed in section 6.2).

---

16 The knowledge ... is considered ... important as evidenced by establishment of schools ... with curricula ... that suggest that formalization of technical knowledge can be taught in abstraction (Weingart 1984).
17 Dual knowledge thesis asserts that there are different roles for science and design (art), where the former relies on logic and rationality, whereas the latter relies on intuition and exhibits idiosyncratic tendencies.
18 Technology is ‘know-how,’ that is, a form of knowledge, and can often precede a clear articulation of ‘know-why.’
March and Smith [1995] propose the categories of construct, model, and method\(^{19}\) as outputs of design research. Constructs form the vocabulary of a domain. They allow ways of conceptualizing a problem and sharing solutions within a research community. Models are sets of propositions or statements that express relationships among constructs. They allow manipulation of constructs by the design researcher. Methods represent steps, algorithms or guidelines, used to perform a task, based on a set of underlying constructs and models. These categories correspond to the notion of ‘frame of reference’ (constructs and models), and ‘techniques’ (methods) in my definition of operational principles. Walls et al.\(^{19}\) define the categories of design product characteristics, and design process characteristics as outputs of design research. These map to ‘frame of reference’ and ‘technique’ respectively in my definition. The definition of operational principles, thus, casts a wide net that can accommodate existing characterizations of knowledge produced by design research. Given the modular nature of design, a single design research project may produce multiple operational principles, some of which may be classified as frame of reference, and others as technique. Walls et al.\(^{19}\) do, however, identify one additional component, meta-requirements. This takes them to the realm of theory, which I discuss next as a distinct output.

6.2 Theory

The top oval (figure 11) represents a metaphorical description of how the artifact would support, control or otherwise influence the phenomenon of interest. This metaphorical representation corresponds to a creation in Popper’s third world [Popper 1968a], that is, it represents an emergent theory about the way the phenomenon of interest ought to be supported by the artifact [Naur 1992]. In a Popperian sense, design artifacts embody ‘good’ theories because they contain prohibitions, that is, they forbid certain things to happen [Popper 1968]. The theory embodied in the artifact may be called a design theory, similar to Walls et al.\(^{19}\), who suggest several characteristics of a design theory. Key among them are goal-orientation (missing from traditional notions of theory) and a prescriptive nature. March and Smith [1995] argue\(^{20}\) that

---

\(^{19}\) They propose a fourth category, instantiation, which corresponds to the realization of the artifact discussed above.

\(^{20}\) March and Smith [1995, p. 254] assert that ‘rather than posing theories, design scientists strive to create models, methods and implementations that are innovative and valuable.’
such theorizing is outside the purview of design research. They state that “given an artifact whose performance has been evaluated [italics introduced], it is important to determine why and how the artifact worked or did not work within its environment. Such research applies natural science methods to IT artifacts. We theorize and then justify theories about these artifacts.” I take issue with this view due to several reasons. First, it takes a post-fact view about artifacts as theories as it postpones theorizing to organizational metaphors only (falling into the trap identified at the beginning of the paper). Second, the evaluation phase that precedes theorizing requires adoption of scientific principles (e.g. for testing hypotheses), for which no theory is specified. It follows that there must be an implicit emergent theory embodied in the artifact. In fact, March and Smith propose several criteria (e.g. completeness, simplicity, elegance), which require a metaphorical understanding of the artifact, that is, as emergent theory.

These emergent theories are made up of a multiplicity of fragmentary components [Orlikowski and Iaccono 2001], each drawing on a narrow, specific view of an aspect of the phenomenon. The theory that is embedded in the IT artifact, then, emerges from a nexus of several theories that contribute to the research process. Possibilities afforded by each contributing theory are realized in innovative ways in the context of other theories. The interrelationships are given coherence through their codification in the artifact. It is in this sense that each claim from this emergent theory is over-determined [Carroll and Kellogg 1989]. Walls et al [1992] describe a similar idea, suggesting design theories as composite theories that encompass kernel theories from natural science, social science and mathematics. They argue that the prescriptive plane provides the common ground for integrating these different types of theories.

A theory, in organizational settings, is defined as a statement of relationships among concepts within a set of boundary assumptions and constraints [Bacharach 1989]. The boundary assumptions include the implicit values of the theorist, which are often the product of the theorist’s creative imagination and ideological orientation or life experiences [Bacharach 1989]. Theories generated by design researchers represent similar outputs. The theories realized in the artifacts are, however, not ‘truths’ that somehow transcend human agency (individual or organizational). They represent normative theories [Abraham 1982]
that may be accepted or rejected by human agents. They differ from social science theories in several ways. First, what is acceptable as legitimate simplification [Constant 1984, p. 35] is different for design theories. This simplification provides the theory (embedded in the artifact) degrees of freedom that may be exercised by the eventual users. For social science theories, on the other hand, complexity is important because they are interested in explaining the richness of the phenomena. Second, the ‘locus of ambiguity’ is different for design theories. Ambiguities that affect overall utility cannot be tolerated. Disagreements among different contributing theories must, therefore, be resolved for the composite theory to work. For social science research, on the other hand, intra-specialty or intra-community debates are more important and those across boundaries are ignored [Constant 1984, p. 36]. A theory proposed by the design researcher is, thus, similar yet different from organizational theorizing by IS researchers.

This realization that there is an element of theory-building in design research responds to Nunamaker’s call for theory-building as a critical phase of research in the IS discipline [Nunamaker 1992]. Interestingly, March and Smith [1995] lament that there are virtually no generalizations or theories explaining why and how (or even if) the artifacts work. Shifting the focus to a theoretical space, as explicated here, should induce design researchers in IS to engage in greater theorizing about the artifacts they design addressing their concerns. Finally, we may distinguish between artifacts (theories) that operate within a single semiotic level or artifacts (theories) that span multiple levels (see Figure 12). These theories, then, suggest different spheres of influence, leading to their characterization as mini-theories or theories of the middle-range or grand theories. Radical inventions that challenge entire technological complexes may then be considered grand theories22 [Constant 1984, Gutting 1984].

The significant outputs of design research, therefore, can be characterized as building of theories, articulating operational principles (knowledge) necessary to realize these, and demonstrating both in the form

---

21 Lyytinen [1987, p. 11-21] identifies several possibilities for theories at different levels that the design researcher may use, explicitly or implicitly.

22 A productive design researcher attempts to balance between well-integrated smoothly working complexes and discontinuous shifts leading to radical inventions [Constant 1984]. A parallel may be drawn here to Kuhn’s notion of paradigms [1970], arguing, for example, that object-orientation represents a paradigm shift.
of artifacts as situated implementations. Table 4 (placed at the end of the paper) illustrates several exemplars of design research, identifying their contributions in the above terms.

7. **Implications**

Unlike research in several other disciplines, whose primary goal is the pursuit of truth, the primary goal of design research in TIS is bringing about improvement in the phenomenon of interest. Design researchers in TIS dare to create virtual artifacts that affect phenomena in the real world. Writings in philosophy of science have not provided adequate attention to this rapidly growing research mode. In this essay, I have attempted to lay out the philosophical foundations of, and outlined a distinct method for design research in TIS. More specifically, I have developed ontological and epistemological foundations of design research in TIS, clarified the outputs of design research in TIS to meet the expectations of research in the sciences, and proposed a set of criteria that may provide evaluation guidelines for design research in TIS.

Several writings over the last few years have discussed and explicated research methodologies for different forms [Orlikowski and Baroudi 1991] of research in IS. These include case studies [Lee 1989], interpretive research [Walsham 1995], empirical research [Benbasat and Zmud 1999], and action research [Baskerville 1999]. In spite of these (or perhaps due to these) the argument from Galliers and Land [1987] still holds true. The primacy of traditional research approaches at the expense of less conventional ones remains a problem in the IS discipline. Banville and Landry [1989] suggest that the IS field is better understood as a fragmented adhocracy, which may be better served by methodological pluralism. This pluralism in the discipline has been long recognized [Galliers 1992, Banville and Landry 1989]. This essay extends the discourse by defining the world-view and method for researching the technology of information systems (TIS). Figure 13 maps the proposals in this paper against the constellation of methods in IS, following and extending the framework proposed by Braa and Vidgen [2001].
Figure 13. Design Research vis-à-vis other Modes [Enhanced from Braa and Vidgen 2001]

As the figure suggests, design research requires in(ter)vention in the plane of representation, as it intends to change and predict new organizational action through such intervention. By separating the two planes, and adding an explicit domain of intended influence in the organizational plane, my characterization distinguishes design research in TIS from the allied discipline of computer science (CS). Following March and Smith's [1995] characterization, research in TIS is more focused on ‘what can be effectively automated,’ as opposed to CS, which is focused on ‘what can be efficiently automated,’ with an almost exclusive emphasis on the representation plane. Of the existing research forms, action research [Baskerville 1999] is closest in spirit to design research in TIS. It too, focuses on intervention as a key principle. The key difference between the two stems from the arena for intervention. For action research, it is the organizational setting, leading to theorizing using organizational metaphors. On the other hand, for design research, it is in the world of signs with a view to bringing to realization an artifact, leading to creation of knowledge and normative theories that employ metaphors from the plane of representation.

More specifically, I hope that the paper has identified the representational plane as an appropriate arena for research in the IS discipline. There are, no doubt, several additional forms of research that will allow
us to populate the representational plane, in a manner similar to those explicated for the organizational plane. For example, it is possible to place work on knowledge representation schemes or that dealing with development of ontologies in the corner labeled ‘understanding.’ Other forms are possible as well. Further, it may be possible to apply the arguments developed in this paper to design research in organizational settings. These developments are beyond the scope of this essay.

In conclusion, I hope that the articulation of these foundations will help alleviate concerns raised by Simon more than 30 years ago [1970, p. 56]; answer, partially, the call to theorizing the IT artifact in the context of designing innovative IT artifacts [Orlikowski and Iacono 2001]; and allow colleagues in IS and allied disciplines a fresh perspective with which to appreciate, legitimize and eventually, accept this unique mode of research.

**Acknowledgements**

I acknowledge feedback on earlier versions of this manuscript from Alexander Hars, Ephraim McLean, Dan Robey, Detmar Straub, Veda Storey, Richard Welke, William Robinson, Torsten Priebe, Yair Wand and Mallika Bose. I also acknowledge the influence of discussions with several colleagues and doctoral students at the CIS department at Georgia State University.
References
   University Press, New York. 
68. Orlikowski, W., and C. S. Iacono. 2001. Desparately Seeking the "IT" in IT Research - A Call to 
70. Orlikowski, W. 1992. The Duality of Technology: Rethinking the Concept of Technology in 
   Cambridge, MA. 
73. Popper, K. R. 1968. Epistemology without a Knowing Subject. In Logic, Methodology and Philosophy of 
   Row. New York, NY. 
76. Probert, S. 1997. The Actuality of IS. In IS: An Emerging Discipline. eds. F. Stowell, and J. Mingers, 
77. Reich, E. 1995. The Study of a Design Research Methodology. Journal of Mechanical Design. 117, pp. 211-
   214. 
   Information Systems Research. 7(4). December. Pp. 400-408. 
   Andersen. DeGruyter, Berlin, Germany. 
   Software, Inc. 
   Vigilant EIS. Information Systems Research, 3, 1, Pp. 36-49. 
   Monograph No. 4. Coopers & Lybrand, Australia. 
<table>
<thead>
<tr>
<th>Source</th>
<th>Research Question and Classification of Problem (following the categories in figure 3)</th>
<th>Methodology (lack of articulation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moore, S. 2001. A Foundation for Flexible Automated Electronic Communication. <em>ISR</em>. 12(1), Pp. 34-62.</td>
<td>Presumptive Anomaly companies “… set up their computer systems so that they can exchange EDI messages.” “They do not want their topic of conversation to be limited by the EDI standard’s current status, they do not want their conversation partners to be limited by legal contracts, and they do not want the speed at which changes can be made to be limited by the speed at which large changes can be made to their computer systems” (p. 34-35)</td>
<td>“This paper describes in detail an approach to computer-processable messaging.” (p. 35)</td>
</tr>
<tr>
<td>Krishnan, R. et al. 2001. On Heterogeneous Database Retrieval: A Cognitively Guided Approach. <em>ISR</em>. 12(3), Pp. 286-303.</td>
<td>Perceived from the Environment, and/or Presumptive Anomaly “The Internet has made the multidatabase problem … more relevant and challenging. Retrieving information from multiple databases generally involves complexities that do not exist when retrieving information from a single database.” (p. 1)</td>
<td>… we propose novel solutions at the logical design level… (p. 1)</td>
</tr>
<tr>
<td>Konana, P., A. Gupta, and A. B. Whinston. 2000. <em>ISR</em>. 11(2). Pp. 177-196.</td>
<td>Functional Failure of Current Technology, and Presumptive Anomaly “…commercial databases are not designed to support timeliness criterion because they do not provide no support for prioritization and dynamic resource allocation schemes.” (p. 178)</td>
<td>“… we develop a social welfare model for pricing RTDB services within organizations.” (p. 181)</td>
</tr>
<tr>
<td>Dey, D., and S. Sarkar. 2001. Modifications of Uncertain Data: A Bayesian Framework for Belief Revision. <em>ISR</em>. 11(1), Pp. 1-16.</td>
<td>Functional Failure of Current Technology “… relational databases do not handle incomplete and uncertain data in a comprehensive manner. … In many real-world applications, however, the available data are often uncertain …” (p. 1)</td>
<td>“We use a Bayesian framework for developing a revision scheme …” (p. 2)</td>
</tr>
<tr>
<td>Mookerjee, V., and M. Mannino. 2000. Mean-Risk Trade-Offs in Inductive Expert Systems. <em>ISR</em>. 11(2), Pp. 137-158.</td>
<td>Cumulative Improvement “Most inductive expert systems are designed under the assumption of a risk-neutral decision maker.” (p. 137), “Despite the apparent link between value-sensitive induction and risk, there is little published work on risk-aware inductive systems” (p. 138).</td>
<td>“… goal is to develop a suitable measure of risk so that risk can be factored into inductive system design.” (p. 138)</td>
</tr>
<tr>
<td>Codd, E. F. 1970. A Relational Model of Data for Large Shared Data Banks. <em>CACM</em> 13(6): 377-387.</td>
<td>Technological Discontinuities “… the problems treated here are those of data independence – the independence of application programs … from growth in data types and changes in data representation …” (p. 377)</td>
<td>“This paper is concerned with the application of elementary relation theory to systems which provide shared access to large banks of formatted data.” (p. 377)</td>
</tr>
</tbody>
</table>
Table 2: Exemplars – Design Research in TIS as Intervention in Semiotic Levels

<table>
<thead>
<tr>
<th>Source</th>
<th>Intervention in Semiotic Levels *</th>
<th>Intervened</th>
<th>Affected</th>
<th>Intervention</th>
</tr>
</thead>
</table>

* Most design research in the technology of IS focuses on intervening and/or affective the levels *Empirics, Syntactics, Semantics and Pragmatics*. Few studies in the technology of IS focus exclusively on the highest level, that is, ‘*social world*’ or the lowest level, that is, ‘*physical world*’. The former are fall within the domain of organizational and human studies, the later within the purview of disciplines such as computer science and engineering.
Table 3: Exemplars – Phenomenon and Artifact in Design Research in TIS

<table>
<thead>
<tr>
<th>Source</th>
<th>Phenomenon</th>
<th>Artifact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moore, S. 2001. A Foundation for Flexible Automated Electronic Communication <em>ISR</em> 12(1), Pp. 34-62.</td>
<td>Initial “Certainly e-mail and telephones and face-to-face meetings … provide flexible communication avenues… However, the cost of this flexibility is that people have to be intimately involved in the communication process – slowing down the whole process and introducing inconsistencies in message handling” (p. 35) Final “… this whole approach is appropriate for automating electronic commerce and dividing the message interpretation procedure into pieces … is beneficial …” (p. 52)</td>
<td>Initial “… what is not available is a language whose message are fully formal, whose meaning is formally defined and implementable …” (p. 36) Final “After the system verifies that the message has correct number of fields … the standard system begins to formulate a response. … the FL-SAS and the MMS specify that message responses rely on inferences drawn from the messages’ meaning and not simply its form.” (pp. 52-53)</td>
</tr>
<tr>
<td>Krishnan, R. et al. 2001. On Heterogeneous Database Retrieval: A Cognitively Guided Approach. <em>ISR</em>. 12(3), Pp. 286-303.</td>
<td>Initial “The process of accessing multiple heterogeneous databases is a knowledge-intensive task. Humans perform this task well.” (p. 289) Final “While the human multidatabase-access provided considerable insight, we…found that that observed problem-solving was … inefficient. … we developed … models and components to address … problems.” (p. 301)</td>
<td>Initial “… we begin with an example that illustrates the capabilities we desire in our information retrieval agent.” (p. 286-287) Final “… InfoB divides the query task into three main stages … InfoB selects those companies who meet the condition …” (p. 300)</td>
</tr>
<tr>
<td>Konana, P., A. Gupta, and A. B. Whinston. 2000. <em>ISR</em>. 11(2). Pp. 177-196.</td>
<td>Initial “… RTDBs, where the utility is measured by the responsiveness to user queries, play a central role in organizations by providing timely access to relevant information. … However, commercial databases are not designed to support timeliness criterion because they do not provide no support for prioritization and dynamic resource allocation schemes.” (p. 178) Final “We apply priority pricing mechanisms to manage negative externalities in the operation of RTDBs as an alternative to complex congestion control and scheduling techniques suggested in the RTDB literature.” (p. 193)</td>
<td>Initial “… using social welfare prices has the advantages of maximizing organizational benefits from computing resources … We focus on externality pricing to influence users’ decisions regarding the level of their usage…” (p. 181) Final “…adaptation of the results from the analytical model as an online admission control and scheduling technique … for real-time databases … The model generates the priority-price-delay schedule.” (p. 194)</td>
</tr>
</tbody>
</table>
Table 4: Exemplars – Outputs of Design Research in TIS

<table>
<thead>
<tr>
<th>Source</th>
<th>Implementation</th>
<th>Knowledge</th>
<th>Theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Konana, P., A. Gupta, and A. B. Whinston. 2000. ISR. 11(2). Pp. 177-196.</td>
<td>“We implemented a computer simulation model …” (p. 186)</td>
<td>Frame of Reference “model for pricing RTDB (real-time database) services within organizations” (p. 180) Technique application of the model for dynamic price recomputation, simulation of the model by relaxing modeling assumptions for integrating within a database environment Symbol Manipulation Techniques Mathematical models, Queuing models, Discrete event simulation (p. 181-185)</td>
<td>Emergent Theory “a priority pricing mechanism to manage negative externalities in the operation of RTDBs that provide timely services to users within organizations.” (p. 177) Component Theories Social Welfare pricing (transfer pricing) from Economics</td>
</tr>
</tbody>
</table>