Theorizing in the Sciences of the Artificial[1]

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ABSTRACT

This essay extends Simon's arguments in the 'Sciences of the Artificial' to a critical examination of how theorizing in Information Technology disciplines should occur. The essay is framed around a number of fundamental questions that relate theorizing in the artificial sciences to the traditions of the philosophy of science. The paper argues that theorizing in this relatively new form of science should be considered in a holistic manner that links two modes of theorizing: an ***interior mode*** *with the* ***how*** *of artifact construction studied and an* ***exterior mode*** *with the* ***what*** *of existing artifacts studied. Unlike some representations in the design science movement the paper argues that the study of artifacts once constructed can not be passed back uncritically to the methods of traditional science. Seven principles for creating knowledge in IT disciplines are derived analytically: (i) artifact system*

[1] This paper is an extended version of Gregor, S. (2009). Building Theory in the Sciences of the Artificial. DESRIST'09, May 7-8, Malvern, PA, USA.

centrality; (ii) artifact purposefulness; (iii) need for design theory; (iv) induction and abduction in theory building; (v) artifact construction as theory building; (vi) holistic linking of interior and exterior modes of theorizing; and (viii) recognition of issues with generality. The claim is that consideration of these principles will improve knowledge creation and theorizing in design disciplines, for both design science researchers and also for researchers using more traditional methods and that attention to these principles should lead to the creation of more useful and relevant knowledge. Examples of application of the principles in the area of Decisions Support Systems are provided in support of the arguments advanced.

Keywords

Philosophy of Science, Philosophy of Technology, Design Science, Sciences of the Artificial, Practical Sciences, Theory, Theory Building

INTRODUCTION

From the last half of the twentieth century onwards there has been an exponential increase in knowledge surrounding technology, including developments not only in information technology (IT) but also in areas such as bio-engineering. These new and complex technologies have not only altered the way many people live and work, but also pose challenges to how we systematically accumulate and disseminate knowledge. It is not clear that the methods that have been used in the traditional sciences, either natural or human science, translate directly to the “artificial sciences”. Thus, this essay continues Simon’s quest, described in *The Sciences of the Artificial* (1996):

> *We need a science of design – intellectually tough, analytic, partly formalizable, partly empirical and teachable.*

In Simon's terms, the sciences of the artificial "are concerned not with the necessary but with the contingent – not with how things are but with how they might be – in short, with design" (Simon, 1996, p. xii). In these practical sciences, such as agriculture, medicine and information technology, useful knowledge is required for people to do things in the world; when they act and construct artifacts to achieve some purpose. The artifacts range from improved crop cultivation methods, to surgical procedures, to drugs and to computer software, hardware and systemized processes (methods) for organizing and managing IT (Srasser, 1985).

Simon's seminal work, however, allows for further examination and extension. Simon and subsequent work in design science has focussed on knowledge concerning the building of artifacts and has tended to treat the study of artifacts once constructed as something that should be passed back to traditional science methods (Hevner et al., 2004; March and Smith, 1995). In contrast, the premise of this paper is that we need to consider theorizing in a holistic manner across the whole of a science of the artificial, both in the building and the observation of artifacts.

To this end the paper addresses some fundamental questions:

1. How can theorising in the Sciences of the Artificial be understood in comparison with other branches of science?
2. Does the scientific method apply to the Sciences of the Artificial?
3. How can we think holistically about theorizing in the Sciences of the Artificial?

4. Do the Sciences of the Artificial present special challenges for theorizing?

The paper proposes the linkage of theorizing in an interior mode, in the design and development of the inner environment of artifacts, and also in an exterior mode, where the artifacts are theorized about in their outer environment. These two modes are seen as “two sides to a coin”; they are intertwined and both contribute to the development of knowledge concerning artifacts in a practical science. The paper differs from prior work in that it applies not only to researchers who personally develop artifacts and theorize about the results in the interior mode (as in some conceptions of design science), but also to researchers who carry out more traditional theorizing about artifacts in the exterior mode, as in a manner common in mainstream Information Systems (IS) journals.

The paper is significant as questions of knowledge creation and theorizing are still relatively unexplored in the design science paradigm in IT fields, despite a rapidly growing literature (see, for example, Carlsson, 2007; Iivari, 2007; Hannay, Sjøberg and Dybå, 2007; Keuchler and Vaishnavi, 2008). Further, processes of theory building and theorizing continue as a subject of debate in other practical sciences. For example, management journals have had a number of issues devoted to the topic of theorizing, including the *Academy of Management Review* (1989, Vol. 4, No. 4), and *Administrative Science Quarterly* (1995, Vol. 40, No. 3), and debate continues (for example, Bamberger, 2008; Locke 2007). Hannay et al. (2007) discuss the place of theory in software engineering.

The contribution of this paper is that it brings together thinking about knowledge creation and theorizing in the artificial sciences paradigm that has, till now, been relatively piecemeal and suggests a framework and a number of important principles for artificial science theorizing. In this respect the paper contributes to the rather sparse extant work in the philosophy of technology (Scharff and Dusek 2003). The essay also has practical significance in that it facilitates the systemizing and capturing of knowledge that informs action and practice in the real world. There is an ethical dimension in that in the practical sciences we produce knowledge that informs actions that can directly affect people's wellbeing, as in the development of safety critical systems. If system failures occur then they can have very real and immediate negative consequences. An overarching aim of the essay is to provide a deeper understanding of how useful knowledge can be developed in rigorous research so as to better inform professional practice.

Some clarification of terms used and the underlying position of the author are required as a further introduction to the paper. Theory is seen in essence as a generalized body of knowledge, with a set of connected statements expressing general relationships among constructs that refer to entities of different types, both real-world and theoretical. It is recognized that views on theory vary and that different types of theory can be distinguished, dependent on the primary aims of the theory; whether analysis, explanation, prediction, or prescription for design and action (see Gregor, 2006).

Further, the essay rests on the adoption of some form of realist ontology, in the sense that the practical knowledge and theory developed are taken to include constructs that refer to entities existing independently of human perception in the real world. A naïve form of realism is, however, rejected, in that our perceptions of the external world are not taken to be unambiguously "true", but should be treated as provisional and liable to error (see Godfrey-Smith, 2003). Epistemologically it is recognized that there can be many approaches to knowledge development.

Much of the argument in the paper applies to a number of the artificial sciences. The focus of the paper, however, is on the disciplines of IT and many of the examples and illustrations are drawn more specifically from IS.

The paper proceeds by directly addressing the research questions that motivated the paper. In the course of the discussion a number of principles are derived to inform theory building in the IT disciplines. Table 1 gives an overview of these principles with their associated research questions as an early orientation to the direction the paper takes. Support for the applicability of these principles is provided in the penultimate section which shows examples from the field of Decision Support Systems.

Table 1: Principles for theorizing in Information Technology as a Science of the Artificial		
No.	Key idea	Principle
Question 1: Nature of Artificial Science?		
1	Artifact system centrality	IT system artifacts are central to theorizing in IT disciplines.
2	Artifact purposefulness	Purposefulness of IT artifacts is recognized and outcomes studied.
3	Need for design theory	Different views of theory are needed, including design theory.
Question 2: Use of Scientific Method?		
4	Induction and abduction in theory building	The importance of induction and abduction in theory building should be recognized.
5	Artifact construction as theory building	Theory building through artifact construction has special features.
Question 3: Holistic View of Theorizing?		
6	Linked theorizing in interior and exterior modes	Holistic linking of interior and exterior modes of theorizing is needed.
Question 4: Special challenges?		
7	Issues with generality	Complexity in IT disciplines entails problems of generality in theorizing.

The Nature of the Sciences of the Artificial?

We begin with the first question posed:

> *How should theorising in the sciences of the artificial be understood in comparison with other branches of science?*

Milestones in the history of the philosophy of science shed light on the place and nature of the artificial sciences. Although tool development (technology) has been a distinctive feature of humankind since its earliest beginnings, the rapid explosion of technological developments in the 20th century is of such comparative recency that its impact on science and scientific method has scarcely had time to be considered in perspective. Such a perspective is what this essay addresses, and it is why it begins with a short overview of stages in the development of science.

Table 2 shows some key points in the history of Western science[2] and accompanying developments in the philosophy of science. Scientific epochs can be distinguished in terms of the underlying phenomena which are studied, with successive epochs providing additional foci of study. Distinguishing these epochs shows how advances in science and corresponding shifts in the philosophy of science have occurred hand-in-hand.

In the early science era, science was not distinguished from philosophy, which dealt with a wide range of phenomena. The Greek philosophers did, however, consider the relationships amongst various fields of knowledge. Loosely understood in modern terms, *epistêmê*, or knowledge, was distinguished from *technê*, or practice (Parry, 2007).

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[2] This very brief outline relies in part on Gribbin (2003) and does not mention developments in Eastern, Byzantine and Arab civilizations during the Dark Ages in Western Europe.

Table 2: Scientific development in Western culture		
Epoch	Science	Philosophy of science
Early science	Primitive, with some steps towards experimentation (Aristotle).	Science not distinguished from philosophy. *Epistêmê* distinguished from *technê*.
Natural Science (17th - 18th century)	Age of Enlightenment/ Age of Reason. Advances in natural sciences (Gilbert, Galileo, Newton, Hooke, Boyle).	Word 'scientist' coined (Coleridge/Whewell), Galileo and Bacon and the scientific method (experiments).
Human Science (19th century)	Sociology (Comte), Psychology (James), Psychiatry (Freud).	"Human science" distinguished by Dilthey (1883) (early interpretivism).
Artificial/ Practical Science (20th century)	Increasingly complex artifacts with invention of computers.	Herbert Simon "Sciences of the Artificial" (1969), Strasser "Practical Sciences" (1985).

With the "Age of Enlightenment" in the 17th and 18th centuries significant advances in science occurred with work by thinkers including Gilbert, Galileo, Newton, Hooke and Boyle. Subsequently, the philosopher-scientist William Whewell invented the word "scientist" in 1833 in conjunction with the poet Coleridge to replace the terms "natural philosopher" and "man of science", which had been used previously (Snyder, 2008).

Another shift occurred in the 19th century with the rise of branches of knowledge concerned with the study of human beings, including psychology and sociology. The term "human sciences" was advanced by the German philosopher Wilhem Dilthey, who:

> *is best known for the way he distinguished between the natural and human sciences. Whereas the primary task of the natural sciences is to arrive at law-based explanations, the core task of the human sciences is the understanding of human and historical life* (Makkreel, 2009).

Advances in technology and the complexity of technological artifacts in the 20th century has been accompanied by increased attention to the philosophy of technology, although this attention is still limited. Simon's *Sciences of the Artificial* (1996), with the first edition in 1969, is the landmark work that seriously considers the nature of the disciplines that deal with phenomena that are artifacts.

The purpose in depicting these different stages in scientific thought is to point out that ideas about epistemology and how science works changed with the phenomena studied. The first 'scientists', Glibert and Galileo, were those who were able to apply the scientific method and compare hypotheses with experiments and observations. For some time science concerned itself mainly with naturally occurring phenomena; such as magnetism, the movement of the planets, electricity and the behaviour of gases. In the 19th century, however, interest grew in sciences concerned with living creatures including humans. Darwin published the *Origin of the Species* in 1859 and the fields of sociology, psychology and psychiatry emerged. Diltthey's concept of the human sciences was important as he saw that the different objects of study meant that the human sciences were relatively independent of the more established natural sciences and that they had to deal with "the more complex networks of the historical world and the actual givens of human beings" (Makkreel 2009). Dilthey's work has influenced thinkers in interpretivism and hermeneutics, including Heidegger, Gadamer and Ricoeur. Even independent of this stream of thought, however, we find questioning as to whether the methods of the natural sciences apply to the social sciences; for example, in concerns with the probabilistic nature of theory (see Nagel, 1979).

We can take this line of thinking further and argue that the fields of knowledge that concern artifacts again require a fundamental and critical examination of how science is conducted. Note that this was also Simon's concern (1996, p. xi);

> *The contingency of artificial phenomena has always created doubts as to whether they fall properly within the compass of science.*

Our overview of the history of the sciences suggests that there is value in distinguishing the sciences of the artificial from other major branches of science, to allow their special features to be carefully examined. The artificial sciences can be seen as constituting a third major form of science, in addition to the natural sciences and the human sciences. This is the view of the philosopher Strasser (1985) who considered the study of artifactual phenomena from the viewpoint of "the phenomenology of scientific life" (p. 55). Strasser favoured the term "practical sciences" rather than "sciences of the artificial" and his definition is that a practical (artificial) science is:

> *a science which is conceived in order to make possible, to improve, and to correct a definite kind of extra-scientific praxis.* (p. 59).

Figure 1 follows Strasser in distinguishing among different types of science, although this categorization is somewhat fuzzy and some fields of study lie across categories. Economics and sociology, for example, have both descriptive (human science) and prescriptive (artifactual) aspects. It is argued, however, that IT disciplines, which are the focus of this essay, fall squarely within the third paradigm of the Sciences of the Artificial.

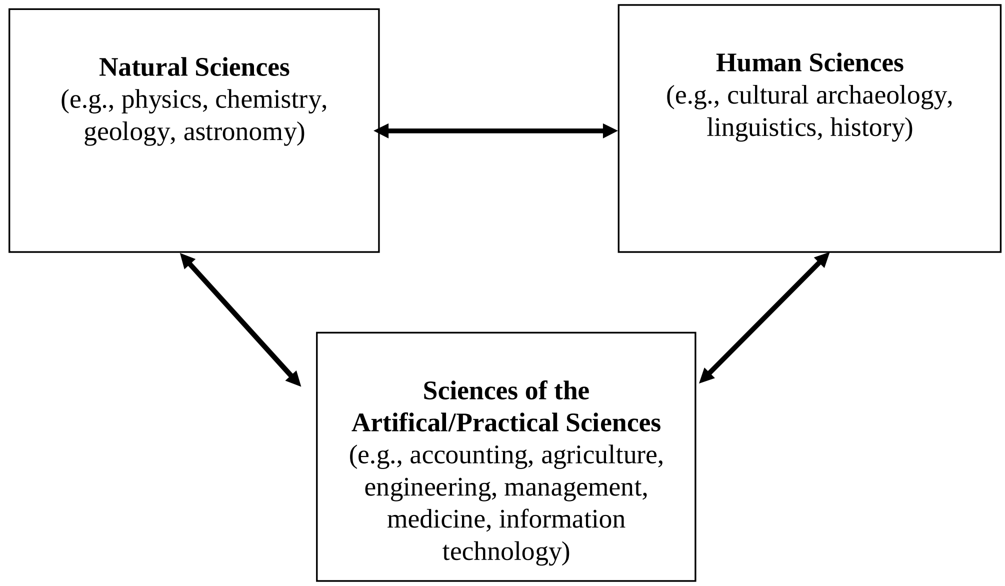

Figure 1. Three Interrelated Forms of Science

A key feature of this perspective is the avoidance of the term "applied science" for those sciences which have, **as their primary aim**, the development of knowledge that guides the construction of artifacts and interventions in the world, as in exemplars such as medicine, agriculture and information technology. In an applied science, the application of knowledge is **incidental**: it is not the primary aim of the science. Distinguishing the artificial sciences separately from other forms of science, including applied science, means that their special nature can be teased out and that the discussion of scientific practice in these fields can become more nuanced.

As a final point, it is noted that the view that the artificial sciences should be recognized as "science" is not universal. Hatfield (2005, p. 946) in the *Shorter Routledge Encyclopaedia of Philosophy* states that "the word 'science' now means primarily natural science, examples of which are physics, astronomy, biology, chemistry, geology and psychology, and it applies secondarily to social sciences such as economics and sociology". There is no mention of the word science applying thirdly to sciences of the artificial, which we will attribute to a narrow and somewhat old-fashioned outlook in the philosophy of science, and not congruent with the broader view of science as being those fields of enquiry that employ methodical empirical methods to investigate and support claims that are made (Gribbin, 2003).

In summary, the answer to our first guiding question is that the sciences of the artificial can be seen as a type of science, but one that likely differs from the natural and human sciences, which each in themselves have developed distinctive modes of enquiry.

To advance this argument distinctive features of the sciences of the artificial are identified using IT as an exemplar discipline and a number of principles are advanced to guide theorizing in IT.

The first principle is taken as axiomatic given the depiction of the Artificial Sciences above and common understanding of the disciplines that are referred to under the umbrella terms of Information Technology or Computing (ACM 2005).

Principle 1: IT system artifacts are central to theorizing in IT disciplines.

An Artificial Science by definition concerns artifacts and we would expect to find an artifact playing a central role in theorizing. This point has been advanced by other researchers. In IS, Weber (1987) argued that further progress required a shift to a paradigm that focused on the study of discrete technology-related artifacts that had longevity. Benbasat and Zmud (2003) suggest that the IT artifact and its related nomological net should form the core of the IS discipline. Iivari (2003) proposed that

IS should be recognized as an engineering-like discipline that develops “meta-artifacts”, which include software packages, development methods and design patterns and principles.

Further, a distinguishing and fundamental feature of the disciplines in IT is that they are intimately concerned with artifacts that are complex systems involving both technical and social components, although the degree of emphasis on the technical versus the social aspects varies across fields. McKay and Marshall (2005), for example, argue for IS as a socio-technical discipline where design science must concern itself with human activity systems, usually technologically enabled. Basic definitions of a computer or information system use words such as input, output, control, feedback and external environment. The first computers appeared after general systems theory had been advanced (Ashby, 1956; Von Bertalanffy, 1968) and relied on many of its concepts. Social science reference theories commonly talk in terms of social systems. Characteristics of systems are: they are open to, and interact with their environment; they acquire new properties through emergence and continually evolve, and; the parts of a system interact to form a whole which is independent of the separate constituents. Systems concepts include the system-environment boundary, input, output, processes, state, hierarchies, goal-directedness, and information (Heylighen and Joslyn, 1992). IT-based artifacts that are systems include a computer program, operating systems, the Internet, an ERP system an online auction and an online social network.

Conceptualizing IT as a science concerning complex system artifacts has a number of implications. That systems need to be treated differently in scientific reasoning and explanation has been argued for by biologists, who are also intimately concerned with systems, albeit those that animated by life. Nagel, 1979, p. 401) gives a comprehensive treatment of this claim and concludes that there are indeed good reasons for differentiating biology from the physical sciences:

> *One is the dominant place occupied by teleological explanations. The other is the use of conceptual tools uniquely appropriate to the study of systems whose total behaviour is not the resultant of the activities of independent components.*

These considerations apply equally as well to the study of computer-based information systems as they do to biology and Simon has used systems theory concepts extensively in the *Sciences of the Artificial*.

As an aside, this first principle distinguishes theory that belongs to IT from reference or kernel theories; theories that can be useful in the study of artifacts, as explanations for artifact behaviour or for design ideas, but do not have an IT artifact as a central place. An example is a theory of interpersonal trust, which belongs as a reference theory to the social sciences, whereas theory about how trust is engendered in online communications could belong to IS.

Taking this foundational principle as a premise leads to a number of the other principles that are subsequently developed, particularly the second principle.

Principle 2: Purposefulness of IT artifacts is recognized and outcomes studied

A distinguishing feature of an artifact is that it serves some purpose, although purposes can be many and varied: for example, a jug has holding liquid as one purpose. This concept dates back to Aristotle in his depiction of the *causa finalis*, the final cause or end of an artifact - “what it is for” - one of the four causes of any thing (Hooker 1996). The artifact’s purpose relates to the context in which it is used.

Heidegger (1993) gave the example of a silver chalice, where in order to understand its purpose, we need to understand the religious ritual in which the chalice is to be used. The purpose of the artifact may not always be that of the original designer and some of its uses and effects may be unintended. Nevertheless, in studying artifacts it is needful to consider the goal, end or aim of the artifact, as originally intended or as arising in use.

Further, given this distinguishing feature, theorizing is more satisfactory if some assessment is made of the outcomes of the artifact's use: whether it achieves a goal or purpose in some way. The constructor of artifacts is usually expected to give some demonstration that the artifact at least works. The observer of artifacts will often evaluate the efficacy or consequences of its use.

This idea finds varied expression across a number of fields. In medicine the evidence-based approach uses the PICO model, where P stands for patient or population, I for intervention (drug or procedure), C for comparison (against what alternatives) and O stands for outcomes (what you can hope to accomplish, measure, improve or affect) (Universities Libraries, 2008). We find something of this thinking also in Van Aken (2005, p. 29) where he says in management design propositions "the independent variable must describe something of value to the organization, like financial performance". In IS, Jarvinen (2007) proposed that we should use a goal function for measuring the goodness of a new artifact. The goal function could cover both intended and unintended consequences of the developed artifact. Hevner at al. (2004) propose that design science research artifacts are constructed to achieve some "end" and must be evaluated against these ends.

It is important to recognize, however, that this principle is important in behavioral-type research studying IT-based artifacts in the exterior mode as well as artifact construction in the inner mode. This principle goes to the core of problems with the relevance of IS research and the “so-what” criteria often applied to research articles. As an example, a researcher might approach a study in knowledge management with a question such as “What methods do knowledge intermediaries apply?” The researcher is likely to produce more significant research, both theoretically and practically, if research questions are also included about the effects of the methods and practices being studied: for example, “Which methods are knowledge intermediaries able to use more effectively in specific contexts?”

Taking this argument further leads to a third principle:

Principle 3: Different views of theory are needed, including design theory.

The conceptualization of IT as a science concerned with artifacts leads us to the question of the place of theory in the Sciences of Artificial. Simon was not much concerned with theory and other researchers in the design science tradition have tended to follow along his path.

The case for different types of theory, however, depending on the purpose of the theorising, is made by Gregor (2006) who distinguished five interrelated types of theory: Type 1 - theory for analysing; Type II - theory for explaining; Type 3 – Theory for theory for predicting; Type IV- theory for explaining and predicting; Type V – Theory for design and action. Gregor and Jones (2007) provide further arguments for recognizing design knowledge as theory and show in detail the structure and components of a design theory (Type V theory). These authors conclude that (p. 312):

The unambiguous establishment of design knowledge as theory gives a sounder basis for arguments for the rigor and legitimacy of IS as an applied discipline. A craft can proceed with copying of one example of a design artifact by one artisan after another. A discipline cannot.

Design theory will include prescriptive statements such as the technological rules of Bunge, which are “an instruction to perform a finite number of acts in a given order and with a given aim” (2003, p. 132). Van Aken (2004, p. 227) expressed these rules as taking the form ‘If you want to achieve Y in situation Z, then something like action X will help”.

The need for design theory as a special form of theory is something that distinguishes the artificial sciences from other sciences. In non-design disciplines such as the natural sciences, Type V theory is not necessary and there is no need for prescriptive statements that will guide design and action.

In IS, the lingering influence of conventional scientific views of theory lead to charges that papers are “atheoretic” if they do not include reference theories of the non-design type. Novice researchers are nervous about doing work that does not have “theory”. An illustration is the plight of a PhD candidate who was investigating project management success. In response to a question as to whether she had considered knowledge of project management methodologies, she replied “but that’s not theory”. Support for a counter argument is provided by published papers in leading journals that do not contain any theory other than design theory (an example is Iversen et al. 2004, where design theory is developed from other design theories).

In other branches of IT, such as Computer Science, the type of knowledge that is here referred to as design theory tends to be unquestioningly adopted as the norm. In Software Engineering there has been recent recognition of the need to explicitly formulate design knowledge as design theory, as in Moody's (2009) work that aims to provide a scientific basis for constructing visual notations (see also Hannay et al., 2007).

Further discussion of problems concerning design theory are discussed under the question of special challenges for the artificial sciences against our fourth question.

APPLICABILITY OF THE SCIENTIFIC METHOD?

The second question addressed is:

> *Does the scientific method apply to the Sciences of the Artificial?*

This question is asked because theorizing at heart relies upon the methods judged suitable for knowledge development. Being scientific is often equated with the use of scientific methods, although the lack of consensus of what is meant by scientific methods is probably as great as the lack of agreement on precisely what the word science means. In very general terms, science is supposed to employ methods that compare "hypotheses with experiments and observation to weed out the wheat from the chaff" (Gribbin, 2003, p. 63).

Possibly the most generally accepted view of the scientific process today is the "hypothetico-deductive method" (H-D method), named by William Whewell in his *History of the Inductive Sciences* (1857), which built upon the work of Francis Bacon in the 17th century. Current forms of the hypothetico-deductive method owe much to the logician Charles Pierce in the 19th century, who combined the H-D method with symbolic logic and recognized three primary modes of reasoning that are at play in scientific enquiry: abductive, deductive and inductive reasoning. The H-D method can be described as (Butts, 1999, p. 409):

Step 1: Explanatory hypotheses or conjectures are generated as a result of earlier inductions, a guess or creative imagination. The hypotheses are accompanied by statements of initial conditions.

Step 2: Predictive hypotheses are deduced from the conjectures.

Step 3: The hypotheses are subjected to experimental or observational tests. If the tests do not support the hypotheses then they are rejected. If repeated tests over time are in agreement with the hypotheses then they can be said to be rendered more probable.

These steps present an idealized form of the theorizing process. Step 1 represents a theory building phase, while Step 2 represents theory testing. This model is presented here in some detail because again there are differences of opinion that impinge on the artificial sciences.

Some divergences in opinion accompany historical shifts in thinking, particularly in regard to the competing claims of induction versus deduction as the dominant mode of reasoning and differences in opinion as to what are the important means of arriving at conjectures in Step 1, the theory building phase. There are different degrees of emphasis in Step 1 upon the importance of induction from evidence versus guesses and creative imagination. Some areas of IT, notably IS, are influenced by what management scholars have to say about theorizing and a number of these scholars have de-emphasized the importance of building inductively upon evidence. For example, Weick (1989) saw theory construction as "disciplined imagination". This view follows Popper, who notably had little interest in where conjectures came from in the first place and was also opposed to the idea that theories became "stronger" as they survived more and more tests, owing to problems with inductive reasoning (Popper, 1980). Although inductive scepticism has a place, the philosophy of science now recognizes views more in tune with earlier views such as those of Bacon, Whewell and Pierce and there are again more varied views on how theory development can occur (see Godfrey-Smith, 2003; Papineau, 2003). There are also differing views of theory building (Step 1) in other areas of the human sciences. Examples include the grounded theory work of Glaser and Strauss (1967). Merton (1968, p. 47), writing about sociological theory, advocated the development of theory on an adequate base of "antecedent empirical enquiry". Further, Bourgeois (1979) provides a description whereby theory of the middle range is generated in a non-linear process with seven steps including theory generation by induction from an empirical base.

There are abundant examples of research in IT disciplines that in essence conform to the idealized form of the scientific process, in both the interior and exterior modes of research, and illustrations are given in the subsequent examples of Decision Support Systems research. Thus, our answer to the second guiding question is affirmative, that the scientific method is evident in the Sciences of the Artificial.

It appears, however, that the scientific method may exhibit special features in this paradigm as views on how the scientific method applies to the sciences of the artificial and technology are mixed. Bunge (1967, p. 174) says that methodologically, technological research "is no different from scientific research". However he presents a rather simplistic view of how solutions to technical problems are invented, ignoring much of the trial-and-error process by which new inventions are developed. Simon (1996, pp. 114-124) limited his discussion of the discovery of new knowledge largely to optimization problems and means-end analysis, where ordinary mathematical deductive logic can be used to identify the best option from a range of identifiable alternatives.

Designers, however, are not confronted only by optimization problems, but also by problems where the range of potential solutions is large and not identifiable at the design point. Such problems can not normally be solved by deductive logic. An engineer faced with the problem of building a bridge over a ravine has no clear guidance from deductive logic as to which design to implement. Often the best that can be done is to think that such and such a design worked in similar situations in the past, and reason inductively to assume that the design is likely to work again in this similar situation. Thus, as has been pointed out by a number of authors, inductive logic is necessary in theorizing about artifacts.

The above reasoning leads to two more theorizing principles for the Sciences of the Artificial.

Principle 4: The importance of induction and abduction in theory building should be recognized.

This principle recognizes that deductive logic continues to be important in theory testing, but that in design disciplines especially the theory building phase is important and must employ induction and abduction in addition to creativity and imagination. The proposal of abduction as an alternate reasoning mechanism is an attempt to understand and describe what practicing scientists do in theory discovery (theory building). Abduction is “inference to the best explanation” and refers to a process in which a hypotheses or theory is developed as the best explanation of data that is available (Vogel, 2005).

Principle 4 stresses the importance of grounding theory development empirically in available evidence, whether it is through the construction of artifacts or in observing what is being done in practice.

This principle has important implications from what is currently seen as "theory development" in IS. It implies that the generation of research models in IS deductively from reference theories for quantitative testing should be done with extreme care and not without some degree of grounding in IT use in practice. Often it appears that researchers have added variables to their models with only slight attention to their importance in something like a "shopping-basket" approach. Reference theories can indicate that a large number of explanatory variables could have some relationship with outcome variables and the inclusion of many variables will lead to more variance being explained in statistical models. This result does not mean that key factors that designers of interventions can manipulate to bring about desired results have been identified. Recent disquiet about the rather ad-hoc extensions to the Technology Acceptance Model (TAM) is an illustration of this problem (see the special issue in Journal of the AIS, 2007, Volume 8, titled Quo Vadis TAM?). Further, the nature of theory building when constructing artifacts deserves elaboration, as discussed below.

Principle 5: Theory building through artifact construction has special features

Theory building through artifact construction, in what is referred to as design science, presents some special challenges for the H-D method. In no branch of science outside the artificial sciences does theory building involve the researcher or others actually constructing the objects of study.

There is an expanding literature on how knowledge development occurs in design fields (for example, Goldkuhl 2004; Peffers et al., 2008). Some literature deals with processes of design and innovation and how designers work in practice and some view design itself as more an art than a science. Atwood, McCain and Williams (2002) give a useful overview of how the design community thinks about design in general, across many fields. Simon (1996) argued against design as a rational decision process and proposed that human designers, when confronted with a myriad of design choices, are likely to settle for good or satisfactory solutions rather than optimal ones. Kuechler and Vaishnavi (2008) provide a good overview of design science in IS. Design science research activities are often described in terms of design-build-evaluate cycles and as a problem solving process. Hevner et al. (2004) utilize a means-end analysis conception of design activity. Other design research activities that can lead to design knowledge include action research and collaborative clinical research (Van Aken, 2005).

The design science literature tends to deal mostly with the first-hand situations where the individual or group constructing the artifact are the same people who reflect on the design and produce design theory. In Van Aken's terms this is the "**developing case study**" approach. However, design theory can also be produced by researchers who reflect at second-hand on what others have done in constructing artifacts. For example, IT professionals can produce artifacts that are new and interesting from a research point of view. For design theory to be produced, reflecting upon what has been done is required (Schön, 1983) and design principles need to be abstracted. This systemization of knowledge gained through practice is a legitimate academic activity and one that has led to a number of influential design theories. For example, Davenport and Short (1990) abstracted ideas from case studies in 19 companies to first depict the general method of business process redesign. Van Aken (2004, p. 232) refers to this type of activity as an “**extracting case study**” or “best-practice” approach and notes that it has produced a number of very powerful technological rules (design theory), such as the Kanban-system and Just-in-Time approaches.

The reasoning that produces design theory after-the-fact from the process of artifact construction is theory building using induction – reasoning from the particular to the general – but does not rely on simple forms of induction (like counting number of instances). The fact that the theorizer can point to the steps in the process that led to the final form of the artifact, possibly showing also why these steps were taken, provides credible evidence of cause and effect.

Further, experimentation in design research can have a different role from that usual in the theory testing cycle of the H-D method. In a building phase, designers think of an idea then try it out informally to see if it works, make a decision then proceed on to other design decisions. This experimentation is part of the process of designing rather than being the experimental method as proposed in science to test cause-effect relationships. In anything more than a trivial design problem the designer will make very many design decisions and it would be infeasible to test every design decision point by conducting a formal experiment.

The argument so far has showed that theorizing in the Sciences of the Artificial in general terms conforms to the idealized form of the scientific method but also that it has some distinctive characteristics and that there are different types of research activities and modes of theorizing. We are thus led to a further question in the following section.

A HOLISTIC VIEW OF THEORIZING?

The third question addressed is:

> *How can we think holistically about theorizing in the Sciences of the Artificial?*

The preceding discussion pointed to some divergent views on theorizing. Particularly noteworthy is the increasing attention paid to design science work, which to some extent is differentiated from "behavioral" or "normal science" type research (see Hevner et al., 2004). The argument here is that it is undesirable to differentiate these two modes too sharply and that in the Sciences of the Artificial they should be recognized as inter-related and part of a greater whole. A special framework is needed for thinking about theorizing in the Sciences of the Artificial, to clearly distinguish it from other types of science and to link the two general modes of research activity and theorizing that are obvious when one examines the research activities that occur. These two modes are termed the interior and exterior modes. The interior mode is where theorizing is done to produce theory for design and action, with prescriptive statements about how artifacts can be designed, developed and brought into being. The exterior mode, includes other types of theory, which aim primarily at analysing, describing and predicting what happens as artifacts exist and are used in their external environment. Depicting these two modes as separate but linked allows us to study them individually but also in relation to one another.

Figure 2 gives a picture of this framework and its chief idea is expressed in a further sixth principle.

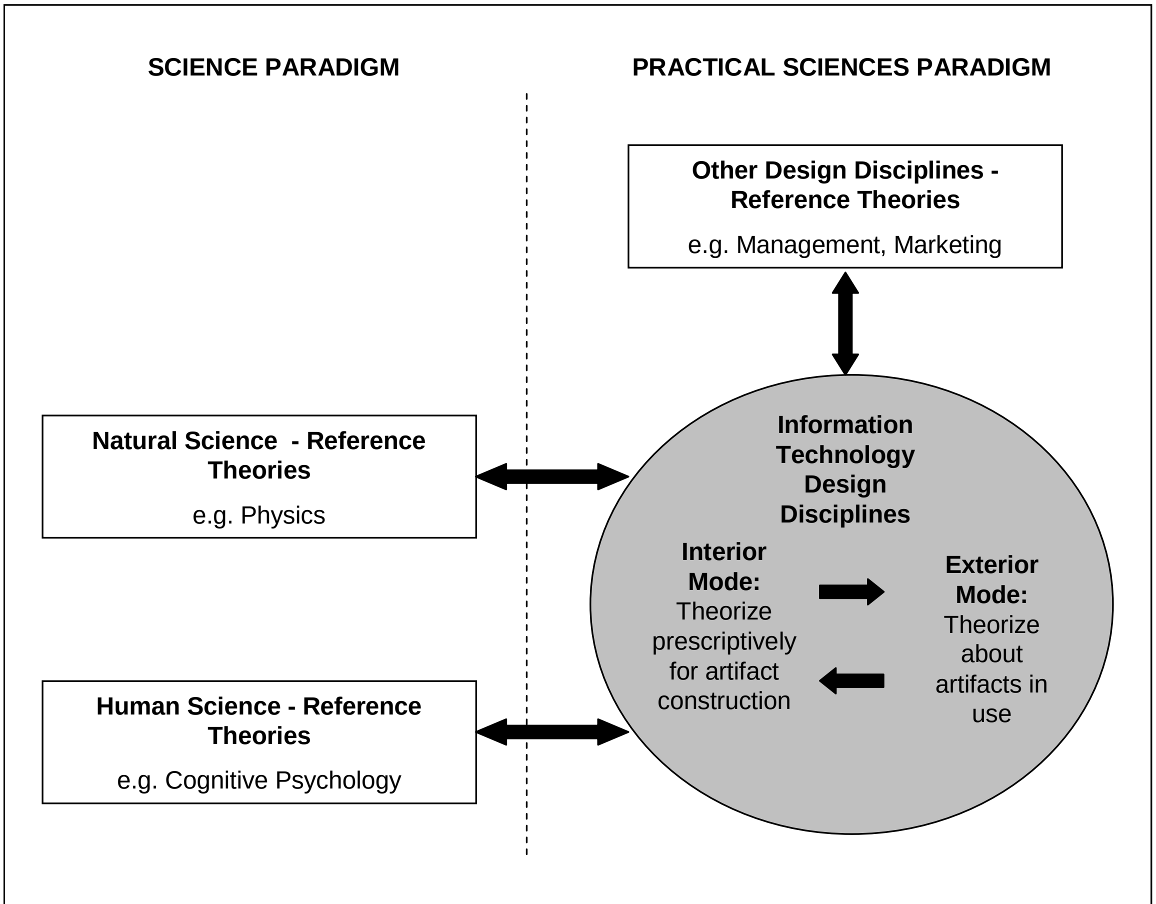

Figure 2. A Holistic Framework for Theorizing in Information Technology as a Science of the Artificial

Principle 6: Holistic linking of interior and exterior modes of theorizing is needed.

This division into two modes of theorizing follows Simon's (1996, p. 7) insights into systems complexity where the division between the inner and outer environment "is highly convenient". The separation of the inner from the outer allows the simplification of tasks. The detail of the inner environment can be hidden when we talk about an artifact attaining its goals and only minimal assumptions may need to be made about the inner environment, as the same end may be achieved by different mechanisms. It is this principle which underlies the mastering of complexity by decomposing hierarchically ordered systems into sub-systems where details of the sub-systems operation are “hidden”. However Simon appears not to think that theorizing methods in the exterior mode are different in the artificial sciences. His view is that:

> *Given an airplane, or given a bird, we can analyse them by the methods of natural science without any particular attention to purpose or adaptation, without reference to the interface between what I have called the inner and outer environments. (p. 7).*

It is here that we part company with Simon’s thinking. As argued under Principles 1 and 2, in IT if we are studying artifacts in the exterior mode, our theorizing is improved if we consider a special feature of artifacts, namely their goal-directedness, and we focus on design features that are linked to the achievement of goals.

These two modes of theorizing are seen as “two sides of a coin”. Both are needed in the design disciplines of IT and they are complementary to each other. Theory in the exterior mode can include propositions such as “A system with feature X will perform better on measure M than a system without feature X”. If empirical testing shows that this proposition is supported then the proposition can be “turned around” or inverted to give a design proposition: “If you want to achieve M then include feature X”. Examples of this type of work abound. For example, Gregor and Benbasat (1999) in a review article of explanations from knowledge-based systems gave a theoretical proposition: “use of explanations helps in learning”. The inverse for design knowledge is that designers of knowledge-based systems should consider an explanation facility if learning by users is a desirable outcome.

It helps to distinguish the two modes in terms of theorizing as they involve different activities and different ways of thinking about theory. Moreover, a single piece of research in a journal article or thesis is likely to include research conducted in either one mode or the other and it is well to consider what is regarded as acceptable theorizing in each mode. A researcher who has devoted a great deal of effort to showing how a new artifact can work, and in showing that it is a novel artifact, might not have the time and effort to do the comprehensive evaluation that would be expected if he/she was working in the exterior mode assessing an artifact constructed by someone else. The IT design science communities would do well to reflect and define their expectations in this respect.

The point of suggesting that the two modes are interlinked and part of a greater whole, however, is that theorizing is improved when the modes are linked and that it is detrimental in design disciplines to lose sight of this fact. Theories overall will improve if researchers in the interior mode pay attention to what researchers discover about their artifacts in use, and researchers in the exterior mode will produce more interesting and relevant work if they focus on knowledge that can inform subsequent design efforts. Recognition of this framework also provides a means of unifying fields in IT and giving them legitimacy as a special form of science, something that is helpful in approaching funding bodies such as the National Science Foundation. In IS, "design science" has in recent times been treated as something that is rather new in mainstream journals and also a separate paradigm from other parts of IS. This treatment has occurred despite earlier descriptions of the "systems development" approach to research (Nunamaker, Chen and Purdin (1990-91) and "constructive research" Iivari (1991), which are earlier terms for design science. Reviews have shown that design-type work constitutes

20-30% of published work in IS, although not always recognized as such (Gregor, 2006; Morrison and George, 1995; Orlikoski and Iacono, 2001) and is thus a sizable proportion of research performed..

SPECIAL CHALLENGES?

The fourth question addressed is:

Do the sciences of the artificial present special challenges for theorizing?

The answer here is “yes” and the challenges are many and varied. In part these challenges stem from the relative newness of the disciplines concerned with complex artifacts, but also to their complexity itself and their rapid evolution.

To take just one of these artifacts, the Web, Hendler et al., (2008, p. 68) note that:

> *The Web is different from most previously studied systems in that it is changing at a rate that may be of the same order as, or perhaps greater than, even the most knowledgeable researcher’s ability to observe it…Web scientists need new methodologies for gathering evidence and finding ways to anticipate how human behaviour will affect development of a system that is evolving at such as amazing rate”*.

The challenges for theorizing are so extensive that they can only be touched upon here. A number of challenges relate to the degree to which generalizations can be made about artifacts. The goal of high-level “grand” theories with wide applicability in IT disciplines is illusive. Perhaps the most likely prospects remain general systems theory and its derivatives, which provide such general statements as the Law of Requisite Variety: only variety in a system’s responses can keep down variety in outcomes when the system is subjected to a set of disturbances (Ashby, 1956). Weber (1997) gives a generalized theory of representation, which aims to model the desirable properties of information systems at a deep level and be a theory native to IS. Peter Denning in computer science has throughout a long career aimed at developing fundamental principles, leading to a set of "great principles of computing" that are general theoretical statements at a high level (Denning and Martell, 2010). An example is "The four base principles of software design are hierarchical aggregation, levels, virtual machines, and objects".

Despite these instances, the imprecise nature of knowledge relating to the behaviour of humans interacting with technology and the changing nature of technologies themselves suggests that highly generalized, unchanging laws as can be found in science may be difficult to formulate in IT design disciplines.

Some authors have advocated an intermediate position of mid-range theory: theory that has moderate coverage and can easily lead to testable hypotheses. Mid-range theory is seen as particularly important for practice disciplines (Merton, 1968), such as IS. Similarly, Van Aken sees that technological rules are not general knowledge, but rather mid-range theories of practice. "They are only valid for a certain application domain, a range of settings that have key attributes in common with the settings in which the rules were developed and tested" (2005, p. 238).

The foregoing leads to the final principle:

Principle 7: Complexity in IT disciplines entails problems of generality in theorizing.

There are other challenges. For example, problems of moving from descriptive to prescriptive statements are explored in some depth by Edgley, who distinguishes between "What is the case?" (questions of fact and science) and "What is to be done?” (questions of action) (1969). Edgley shows that prescriptive statements about action do not necessarily follow from descriptive knowledge. To extrapolate, imperative statements about design and action cannot be deduced from scientific knowledge. For example, as a matter of science one might know that an insecticide kills an insect pest. One cannot deduce from this knowledge that “in order to kill the insect pest one must use insecticide”: there may be other ways of killing the pest. This interesting point has implications for the degree and manner in which theorizing in the exterior mode informs artifact construction and theorizing in the interior mode. However, it is not pursued further at this point.

APPLICATION OF PRINCIPLES TO DSS

The applicability of the seven principles is investigated in the area of Decision Support Systems (DSS), which was chosen as an exemplar as it has been a continuing area of research for a number of decades and has enjoyed some success. Decision Support Systems covers several sub-groupings of work including personal DSS, group support systems, negotiation support systems, intelligent DSS, knowledge management-based DSS, executive information systems,/business intelligence and data warehousing (Arnott and Pervan, 2005). The area includes some of the most highly cited research in IS, with early seminal works such as Keen and Scott-Morton (1978) and Sprague and Carlson (1982) appearing near the top of citation classic lists (see Walstrom and Leonard 2000). DSS is still seen as an area of commercial IT that is booming, especially in data warehousing and business intelligence (Arnott and Pervan, 2005).

Research in DSS is examined for evidence of the seven principles to show how the principles are implicated in successful research progress and also how, in some instances, deviation from the principles has led to problems. This analysis draws upon Arnott and Pervan (2005), Power (2007) and a number of the classic works in DSS. Each principle is examined in turn.

Principle 1: IT system artifacts are central to theorizing in IT disciplines.

Histories of DSS show how the field began with the construction of artifacts employing newly developed computer systems to aid managers in decision making and planning. In an early important step in 1967 Scott-Morton built, implemented and tested an interactive, model-driven decision support tool for his PhD thesis at MIT (Scott-Morton, 1967). The field has continued to focus on artifacts based around IT systems, with the classification into different sub-groups by Arnott and Pervan (2005) showing the different types of systems. Note, however, that many of the systems studied are socio-technical systems, with the human behavior of users studied along with the technologies. Arnott and Pervan (2005, p. 82) conclude from their overview of the field that “Importantly, DSS researchers have maintained a strong recognition of the importance of the IT artifact in IS research”.

Principle 2: Purposefulness of IT artifacts is recognized and outcomes studied

Seminal papers show how early DSS artifacts were developed with some purpose in mind, to meet a perceived need, and that evaluation of the artifacts against these needs occurred. Scott-Morton (1967) developed a production planning system with the purpose of helping managers make recurring decision and studied outcomes of its use with experiments. Dennis et al. (1988) report on an electronic meeting system PLEXSYS, which was developed with the aim of shortening “the lifecycle of development by facilitating a fast implementation of a prototype system” (p. 622).

Use of PLEXSYS was studied in a large multinational firm over a one-year period and outcomes reported of "fewer meetings" and "fewer person-hours" for projects supported by PLEXSYS (p. 613). Interestingly, Arnott and Pervan (2005, p. 82) report that in their period of study 1990 to 2003, a "major omission in DSS scholarship was the poor identification of the clients and users of the various DSS applications that are the focus of investigation". Their conclusion is congruent with the belief that good theorizing should explicitly identify the purpose or aim of IT artifacts, as identification of clients and users and the context of use is necessary for a full understanding of the purpose of an artifact.

Principle 3: Different views of theory are needed, including design theory.

Much of the theory that has been developed in DSS is design theory, whether or not explicitly labeled as such, and other types of theory are also evident. The seminal works by Keen and Scott-Morton (1978) and Sprague and Carlson (1982) are important because they containing design principles (theory) for building DSS. Sprague and Carlson (1982) in their classic work propose architectural principles for a DSS, with the primary components of data base, model base, dialogue generation and management software. Design method principles are also provided to guide the construction of DSS. Other types of theory are evident with Simon's books on management decision making used as reference theory (Simon, 1947; 1960).

Principle 4: The importance of induction and abduction in theory building should be recognized.

Many significant papers in DSS report studies where induction and abduction has been used as a base for developing theory. A large proportion are the developing-case-study type where an individual or group first-hand produces an artifact and reflects inductively from observation of its use (as in the PLEXSYS system described by Dennis et al., 1988). Grohowski et al., (1990) reason inductively and abductively about the use of their electronic meeting systems (EMS) at IBM at 33 sites with over 15,000 people over 3 years to derive some success factors for DSS: for example, "anonymity is particularly beneficial in the meeting process" (p. 377), and; "the meeting room environment should match the characteristics of the group" (p. 378). There are also characteristics of the "extractive case study", where design principles that were not originally conceived for the artifact have been extracted from observing the artifact in use: for example, "EMSs help provide an organizational memory concerning related meetings" (p. 379).

Arnott and Pervan (2005) report that design science (description of an application or system) was the predominant type of research in the sample of DSS papers they studied, thus supporting the argument for the place of inductive reasoning from instances of artifact construction in DSS research. They offer additional support for the need for this principle when they ascribe the current "crisis of professional relevance" they observe in part to a lack of case studies of DSS that illuminate areas of contemporary practice. Case studies, especially the interpretative case studies they recommend, employ inductive rather than deductive reasoning.

Principle 5: Theory building through artifact construction has special features

Interestingly, one of the first important papers in IS that proposed artifact construction as a special but legitimate form of research activity and theory building arose in the decision support systems field itself. Nunamaker, Chen and Purdin (1990-91) described a "systems development approach" that included cyclic steps of theory building (conceptual frameworks, mathematical models and methods), systems development, experimentation and observation following experiences with group DSS research at the University of Arizona.

First-hand accounts show that creativity and imagination in steps of iterative development and trial-and-error are used in DSS artifact construction rather than deductive reasoning from prior theory. Dennis et al. (1988) provide a history of the PLEXSYS project at the University of Arizona and list a succession of software tools, initially for automating the systems development process in 1965 and then for group meeting facilities in 1984 and 1987. It is stated that the early stages of thinking about process of requirements determination depended on “collective wisdom” at the time (p. 620), rather than prior theory. Some of this collective wisdom later turned out to be wrong, as in the assumption that the individual or group responsible for the system building project was capable of specifying their requirements, which was only recognized through experience.

Principle 6: Holistic linking of interior and exterior modes of theorizing is needed.

The field of DSS provides ample evidence of theorizing in both interior and exterior modes. The examples above from the PLEXSYS project show how theory was developed for group DSS in developmental work where artifacts were constructed (interior mode). An example of theorizing in the external mode is the review paper of explanations by knowledge-based system by Gregor and Benbasat (1999), which formulates theory of the conventional explanatory-predictive type, with formal testable propositions and support from reference theories including cognitive psychology and Toulmin’s model of argumentation. As noted previously, the propositions in this theory can be inverted to give guidance as design principles.

Arnott and Pervan (2005) report that after descriptive studies of artifact (design science), experiments with DSS are the next largest category of research, and note that the field has a well-balanced mix of development, technology, process and outcome studies.

Principle 7: Complexity in IT disciplines entails problems of generality in theorizing.

DSS research provides interesting insights into the problems and issues with developing high-level general theory. In fact, even the early work provided high-level general statements in the form of design principles such as those evident in the specification of the architecture for a DSS (Sprague and Carlsson, 1982). It is not clear, however, that the field has been able to build on the early knowledge in a cumulative fashion. Arnott and Pervan (2005) see a problem of research inertia, with the earliest sub-fields from 30-40 years ago still dominating quality research publication and a failure to move on and study important theoretical issues in newer sub-fields such as data warehousing and business intelligence.

Possibly the field has also not been energetic enough in efforts to identify and promote principles and theory that do have very wide-ranging applicability. A good example is the reflection on the discovery of the difficulties in obtaining “correct” requirements specification by Dennis et al. (1988) in their brief history of electronic meeting systems at Arizona. It is noted that an initial assumption in the 1960s in the initial design and development project was that requirements were known, or “the individual or group responsible for the systems building project was capable of stating the requirements … The emphasis on involving the user in requirement analysis was not to develop for another ten years” (p. 620). Unfortunately, the high-level principle that users should be involved in specifying requirements is still not sufficiently recognized and research 30 years on finds that many developers are building intelligent DSS with little or no idea of what users' needs are (see Lynch and Gregor, 2004). Possibly a problem here is the continuing reluctance to recognize design knowledge as theory and to devote attention to identifying and specifying high-level design principles, unlike the efforts in Computer Science by Denning (Denning and Martell, 2010).

CONCLUDING REMARKS

This essay addresses complex issues, those of knowledge creation and theory building, and it does so from the point of view of the sciences of the artificial (alternatively referred to as practical sciences or design disciplines), a perspective which has been little considered. Thus, the arguments made are advanced for discussion and to further debate, rather than being regarded as fixed and certain ideas. There are many new ideas appearing in the literature of the artificial sciences, which as a study of the design of complex artifacts dates back only for about 50-60 years. It is expected that it will be some time before a common understanding and means of describing our problems emerge. This essay is just one step along the path.

The essay was framed around a number of fundamental questions in order to place theorizing in the artificial sciences against the broad tradition of the philosophy of science. Addressing these questions has led to a general framework (Figure 2) within which a number of approaches to theorizing can be seen as complementary and to a number of high-level principles for theorizing (see Table 1).

In answer to our first driving question, it is concluded that the artificial sciences are a third broad form of science in addition to the natural and human sciences. The artificial sciences can be regarded as a science because they use scientific-type methods of observation and experiment to test theory. It is sensible to distinguish this third category, however, because it has features that make theorizing different from other categories of science. That is, artificial science theory concerns artifacts that are constructed with some purpose and in theorizing it is needful to study the relationship between the means of achieving some outcome and the outcome which is achieved. A special type of theory with prescriptive statements, design theory, is needed to capture the knowledge developed. Principles 1, 2 and 3 resulted from these ideas.

The second question asked whether the artificial sciences followed the scientific method. The conclusion is “yes, but with some special features”. First, it was argued that the artificial sciences require the acceptance of inductive methods in theory building, which is in accordance with some streams of thought amongst philosophers of science, but not all (Principle 4). Further, the processes of theory building can involve steps which do not normally belong to any of the other categories of science: namely the construction of the object of study by the researcher/theorizer or a practitioner (Principle 5). Theory building around artifact construction provides for more sophisticated forms of inductive reasoning.

The third question asked whether a holistic framework is possible for theorizing in an artificial science. The suggestion is “yes”, and following Simon an interior and exterior mode of theorizing are distinguished (Principle 6). Unlike Simon, however, theorizing in the exterior mode is not seen as equivalent to normal natural science theorizing, because, as argued under Principles 1,2 and 3, the objects of study are artifacts and need to be treated differently in theorizing. Design type theory is seen as the ultimate aim of research in the artificial sciences and work in the exterior mode should inform the design theory generated in the interior mode.

The fourth question asked whether there are special challenges for theorizing in the artificial science. The answer again is “yes”. The complexity and rate of change of modern technologies stretch our abilities to formulate general and high-level theory. The theory that is developed is liable to be limited in its scope and in the level of generalization possible, and also in the time it retains currency (Principle 7).

Some evidence for the worth of the seven principles is provided by examining the field of Decision Support Systems, a fruitful and successful area of research, where all seven principles can be identified and moreover, apparent departure from the principles in some respects can be linked to problems.

A limitation of the paper is that it does not cover in detail questions of theory building and research methods. Thus the advantages and limitations of different research approaches are not discussed. At heart the essay is a result of analytic reasoning; the principles derived are arrived at by logical extension from the defining characteristics of IT and its nature as a design discipline.

The contribution of the paper is that it provides a high-level framework for thinking about the different types of theorizing in the paradigms of natural science versus that of design. Many of the ideas in the paper stem from Simon’s seminal work, yet there are differences, particularly in the identification of the need for inductive logic. Further, Simon did not give much thought to the actual process of theorizing and both he and subsequent writers have not explicated the special features of theorizing in the exterior mode in a design discipline.

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