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ITB12820

This paper appears in the book, *Emerging Trends and Challenges in Information Technology Management, Volume 1 and Volume 2* edited by Mehdi Khosrow-Pour © 2006, Idea Group Inc.

A Framework for Design Science Research Activities

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ABSTRACT

Design Science (or Design Research) as a research paradigm has been underemphasised in IS research in favour of empirical research using the Positivist and Interpretivist approaches of Natural and Social Sciences. It also has not been very well integrated with other research approaches. The conduct of Design Research provides an excellent opportunity for the IS field to increase its relevance to practice in industry. This paper refines our current understanding of Design Research and its relationship to other research approaches or paradigms. It proposes a revised framework for understanding the activities of Design Research, which also relates Design Research activities to research conducted in other paradigms. The framework emphasises the role of theory building and the form of design (utility) theories, but also generalises on activities for evaluating solution technologies in either positivist or interpretivist frames.

1. INTRODUCTION AND OVERVIEW

In Information Systems, research methods and particular pieces of research have commonly been divided into positivist, interpretivist, and sometimes into critical research paradigms (e.g. as in Galliers, 1991). However, such divisions overlooked another research paradigm that is essentially creative and oriented toward problem solving. Recently, Design Science (or Design Research) has received considerable attention and advocacy (e.g., Hevner et al, 2004, Vaishnavi & Kuechler, 2004/5, and Au, 2001).

The emphasis in this paper is on Design (and development) as the *research method* and *research paradigm* instead of on Design as the *topic* of the research (unlike, e.g., the online journal *Design Research*). Such research invents or creates new or improved means to address relevant problems. Explicit examples of Design Science (or Design Research) include Walls et al (1992) and Markus et al (2002). However, much research has been conducted within the IS field that has not used either term to identify itself, such as research developing Group Decision Support Systems (e.g., Dennis et al., 1988). Further, many artefacts have been designed and developed in IS research that are not computer-based systems, such as methods, techniques, notations, and tools for IS/IT development, planning, and management. Well known examples of these include procedures for database normalisation (e.g., Codd, 1970), the Unified Modelling Language (UML) (e.g., Rumbaugh et al, 1998), and the ServQual instrument (Pitt et al, 1995).

Research using Design Science as a research paradigm and method offers the IS Field its greatest chance to increase its relevance to industry practice and to society because it directly helps to solve their problems. However, further work is needed to extend our understanding of the practice and relevance of Design Science Research. Ultimately, guidelines for conducting Design Science are needed to guide novice researchers. This paper considers how the research activities in a Design Science paradigm relate to the other research paradigms identified above, in terms of their interaction and complementarity in actual research practice.

Section 2 reviews the state of guidance for conducting Design Science Research in information systems. Section 3 proposes a framework for understanding and relating the activities of Design Science, as well as other complementary research approaches/paradigms.

2. DESIGN SCIENCE RESEARCH LITERATURE

Design Science has its roots in engineering and other applied sciences. An important foundation is Herbert Simon's conceptualisation in The Sciences of the Artificial (1996, first published in 1969). Simon noted that "Schools of architecture, business, education, law, and medicine, are all centrally concerned with the process of design." Clearly this includes the 'school' or entire field of Information Systems. The other 'schools' cited above provide potential exemplars (or reference disciplines) upon which the IS field could (and often does) draw guidance and inspiration. Simon goes on to note that such schools can achieve their purpose (and establish their credibility) "to the degree that they can discover a science of design, a body of intellectually tough, analytic, partly formalizable, partly empirical, teachable doctrine about the design process." In a sense, this sets out an important agenda for IS research.

March and Smith (1995) took up Simon's gauntlet. They noted that Design Science needs to undertake two main processes in a cycle: *Build* and *Evaluate*. The build process recognises the important step from design (which is commonly considered to be an abstract activity) to build, which is a physical (in at least some sense) realisation of the design.

March and Smith (1995) also identified four design artifacts or deliverables created by design science research: *constructs*, *models*, *methods*, and *instantiations*. Constructs are the elementary concepts of the problem/solution space. Models include relationships among relevant constructs. As such, they are similar to theories. Methods specify how to perform a (design) task. The product of such a task would be a design. Instantiations are the realisations of designs as physical or abstract products. Such a product could then be applied in an organisational situation.

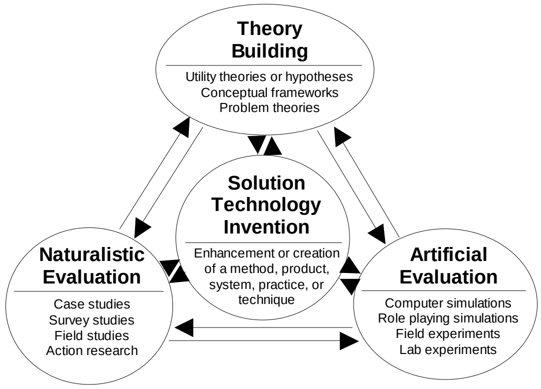
Rossi and Sein (2003, in acknowledged collaboration with Purao) added a fifth design artifact or research deliverable, that of *better theories*.

Hevner et al (2004) represents the most recent and accepted statement of the IS field's conception of Design Science in IS research. The authors draw on the earlier work of March and Smith (1995) and develop an overall framework of IS research as well as guidelines for the conduct and reporting of design science research. They extend the dual cycle of March and Smith (1995), renaming the two main processes *Develop/Build* and *Justify/Evaluate*. IS Design Science Research should be informed by both *Business Needs* and *Applicable Knowledge* (existing theoretical knowledge). The products of Design Science in IS research include both applications of the new instantiations to business/organisational environments and additions to the theoretical knowledge. The quality of these two products corresponds respectively to relevance and rigour. However we note that none of the above authors addressed the form of theories or theoretical knowledge or how they are developed during the research process.

3. A FRAMEWORK FOR DESIGN RESEARCH ACTIVITIES

Nunamaker et al (1991) proposed a framework or model for contextualising the role of system development in IS Research. Although this was an early paper in Design Research, they didn't use that term. They were mainly concerned with "instantiation" of information systems (in particular GDSS). Their research framework included four

Figure 1. Framework and context for design research



(adapted from Venable & Travis, 1999 after Nunamaker et al, 1991)

areas of research activity: (1) theory building, (2) system development, (3) experimentation, and (4) field studies. Nunamaker et al (1991) focussed only on computer-based systems as their (implied) design artifact. Their paper was written at a time when qualitative research methodologies were only beginning to gain broader acceptance in IS research. Therefore, qualitative research methods were not incorporated into their framework.

Venable and Travis (1999) extended the design artifact to include system development methods (part of the topic of their paper), renaming 'field studies' as 'in situ investigation', and adding 'action research' to the field studies side and 'role playing simulations' (the research method in their 1999 study) to the experimentation side. However, the system development activity from the Nunamaker et al (1991) framework was not fully generalised. Also, the distinction between experimentation and in situ investigation was also not made clear.

To address the above shortcomings, this paper proposes a revised framework (see Figure 1), which includes activities of (1) theory building, (2) solution technology invention (rather than the more specialised 'system development'), (3) artificial evaluation, and (4) naturalistic evaluation.

Solution Technology Invention is the core of Design Science Research. A solution technology is any approach to making an improvement in an organisation, including information systems, information technology, systems development methods, algorithms, managerial practices, and many other technologies or techniques. Solution Technology Invention involves the high level and detailed design, building, and possibly functional testing of a hypothesised solution technology.

Any or all of the activities in Figure 1 may be part of a particular piece or programme of research. The arrows show that, over time, one can alternate between the different activities as research design or enactment demands dictate. The different activities involve multiple research methods and paradigms and, in the opinion of the author, should not be performed in isolation. While the arrows show complete flexibility to move between the different activities, in practice two main research cycles are carried out. These are discussed further below.

Figure 1 can be related to both March and Smith (1995) and Hevner et al (2004). Whereas both of those papers had only two activities, this paper splits evaluation into two kinds, artificial and naturalistic. It also introduces theory building as a specific activity, rather than being implied (as in Hevner et al, 2004) by theory as a possible outcome (or design artifact) of the research. This section of the paper will first look at each of the four activities, then consider typical patterns or cycles of activity.

3.1 Theory Building

As noted in Hevner et al (2004), design science research is informed both by existing theory and by business needs. This paper asserts that theory building should occur both as a precursor and as a result of design research.

As a precursor to Solution Technology Invention, one should formulate a utility theory or hypothesis of a kind of approach to reduce the problem (Venable, 2006). Utility hypothesis formulation correlates to the use of abductive reasoning as in Vaishnavi & Kuechler (2004/5). Venable (2006) proposes some prototypical forms of utility theories.

- Solution technology X (when applied properly) will help solve problems of type Y
- Solution technology X (when applied properly) will provide improvement of type Y
- Solution technology X (when applied properly to problems of type Y) is more effective, efficacious, or efficient (Checkland and Scholes, 1999) than solution technology Z

Figure 2 (Venable, 2006) gives a visual representation of utility theories. The solution space describes the concepts that embody the solution technology (e.g. Solution Technology X above). The relationships between the concepts in the solution space (arrows in figure 2) may be aggregation or generalisation or possibly of other kinds.

The problem space represents the researcher's understanding of the problem(s) being addressed by a proposed solution technology, specified and placed in context by relationships with other problems and problem aspects. This corresponds to those 'business needs' (Hevner et al, 2004) that the solution technology addresses. The relationships between concepts in the problem space may be aggregation, generalisation, or other kinds, but especially *causal* links.

David Kroenke (citation unknown) gives a concise, but pithy definition of a problem as:

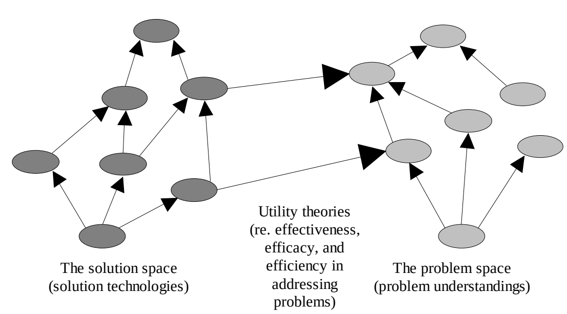
"A perceived difference between what is and what should be" (Kroenke)

A utility theory then links some solution technology concept or group of concepts to the aspect(s) of the problem(s) that it/they address. A solution technology (in the solution space) that helps by eliminating or reducing one or more of the problem causes (in the problem space) is like treating the disease in medicine (e.g. using antibiotics to kill undesirable organisms). A solution technology that helps by compensating for undesirable circumstances or consequences of the problem is similar to "treating the symptoms" in medicine (e.g. cooling someone who has a high fever). The meaning of the utility theory should be specified in terms of the impact (solving problems or providing improvements above) on the problem space, hence the direction of the arrow in figure 2.

Any utility theory proposed should be precise about what problem(s) it addresses, what way it addresses the problem(s) (as above) and what benefit would occur from applying the solution technology.

Because problems are perceived (not part of an objective reality), they are often perceived differently. People may have different understandings of the consequences and causes of 'the' problem and different

Figure 2. Components of utility theories and hypotheses (Venable, 2006)



personal values about what is desirable or undesirable. It is important that design researchers not miscommunicate about our understandings of the problem space. A shared or obvious understanding often does not exist. Clear and complete statements about the problem space being addressed are therefore needed.

Clear and complete statements are also needed on the solution technology side of a utility theory. Each new solution technology is based on or related to other solution technologies that have already been invented, possibly combining them or making small enhancement. Whichever of these, solution technologies are always related to and contrasted with existing approaches. The paper proposes that the same needs to be done in IS Design Research.

In addition to theory building before conducting Design Research, theory building should also be accomplished following solution technology invention and evaluation (at the end of Design Research). Evaluation results in understandings of a solution technology's efficiency, efficacy, and/or effectiveness for solving or alleviating the problem(s). A solution technology is also commonly evaluated in terms of its cost, organisational practicality, and other criteria, relative to other potential means (solution technologies) to solve or alleviate the same problems. These findings all need to be incorporated into theory.

3.2 Solution Technology Invention

In Solution Technology Invention, the core idea of the hypothesised solution technology is thought out and fleshed out in detail. For example, notations for diagrams are developed, descriptions of steps, stages, etc. of new methods or practices are written, or software is developed and tested for correct functioning according to requirements. The development of a solution technology may be just a small refinement(s) of an existing solution technology or it may be the invention of a wholly new, complex solution technology.

The processes for the invention or creation of a new solution technology are as many and varied as the different technologies and the researchers who invent them. The process may involve many small iterations with theory building and evaluation activities, or it may be an entire, top down development approach, with the resulting solution technology not being evaluated until the whole technology is put together (although risk management practice would suggest an iterative approach may reduce costs and the need for rework).

3.3 Solution Technology Evaluation

Once built, solution technologies are still only hypothesised to be useful to address problems unless they are evaluated. It is important that the solution technology, as well as the utility theory upon which it is based, are tested and evaluated.

Solution technologies and utility theories may be evaluated in three main areas. They are evaluated:

- in terms of their effectiveness and efficacy (Checkland and Scholes, 1999) in solving or alleviating 'the problem'
- in comparison to other solution technologies
- for other (undesirable) impacts (cf. Checkland and Scholes (1999) on 'efficacy' in the long run.)

Evaluation research is usually empirical and may use methods from the natural or the social sciences, depending on the nature of the problem and/or solution (purely technical or at least partially social or organisational). This paper proposes two broad classes of evaluation activities: artificial evaluation and naturalistic evaluation.

3.4 Artificial Evaluation

Artificial Evaluation is evaluating a solution technology in a contrived, non-real way. It includes evaluation research methods such as

- Laboratory experiments
- Field experiments
- Simulations

Artificial Evaluation is predominantly positivist, but can also be interpretivist. It may also be classified as critical research, but almost never is. Field experiments are closest to naturalistic evaluation.

The particular steps to be taken in artificial evaluation depend upon the particular research methodology chosen.

3.5 Naturalistic Evaluation

Naturalistic evaluation enables a researcher to explore how well or poorly a solution technology works in its real environment – the organisation. It is the real 'proof of the pudding' in that it includes all of the complexities of human practice in real organisations. Studies of solution technologies in use, but also of technology transfer and adoption of the new technology, can point out new problems introduced by the technology or its introduction. Studies can also focus on organisational or societal impacts, even after a technology has been in use for many years.

Naturalistic Evaluation may be difficult (and costly) because it must discern the effects of many confounding variables in the real world. It may be impossible to compare with other solution technologies, because a project can only be done once with the same people, in the same state of mind, etc.

Naturalistic Evaluation can be conducted using research methods including

- Case or Field studies
- Surveys
- Ethnography
- Action research

Action research is not limited to just evaluation. Action research, like design science research, is oriented toward organisational problem solving. Action research may include the selection of an existing, relevant solution technology and its application. In this case, its relevance to design science would be confined primarily to naturalistic evaluation, but may include theory building, for example to explain deficiencies encountered in applying the solution technology to the problem at hand. However, action research may also include the adaptation or invention of a new or improved solution technology. In this case, action research incorporates the solution technology invention activity.

Naturalistic evaluation is empirical and may be interpretivist, positivist, and/or critical. What is observed or studied are sometimes people's opinions or perceptions rather than the phenomenon itself. For example, successfully solving a problem is often about whether people perceive it to be solved rather than some objectively verifiable phenomenon.

The results of evaluation need to be fed back to the Theory Building activity. Results can confirm or disconfirm existing utility theories. Where results disconfirm existing theories, new or extended theories may be put in their place. Where new organisational benefits or undesirable organisational or societal impacts are found, new theories may be put forward. It is desirable that such new theories should be integrated with existing theories.

4. SUMMARY

Design Research has an important place in IS Research. Recent work on Design Science and Design Research has re-emphasised its importance and role to the IS field, but has not been considered carefully in relation to other research approaches and methods.

This paper has refined ideas about the activities undertaken in Design Research (particularly theory building). Hopefully, the framework provided in this paper is a further step toward the goal of making Design Research more understandable to junior researchers. More work is needed to further refine and test these concepts and develop prescriptive recommendations for conducing Design Science Research

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