

Research Methodologies, Innovations and Philosophies in Software Systems Engineering and Information Systems

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Published in the United States of America by
Information Science Reference (an imprint of IGI Global)
701 E. Chocolate Avenue
Hershey PA 17033
Tel: 717-533-8845
Fax: 717-533-8661
E-mail: cust@igi-global.com
Web site: <http://www.igi-global.com>

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Library of Congress Cataloging-in-Publication Data

Research methodologies, innovations, and philosophies in software systems
engineering and information systems / Manuel Mora ... [et al.], editors.
p. cm.

Includes bibliographical references and index.
ISBN 978-1-4666-0179-6 (hardcover) -- ISBN 978-1-4666-0180-2 (ebook) -- ISBN
978-1-4666-0181-9 (print & perpetual access) 1. Software engineering. 2.
System engineering. 3. Research--Methodology. 4. Information technology. I.
Mora, Manuel, 1961-
QA76.758.R467 2012
005.1--dc23

2011044987

British Cataloguing in Publication Data

A Cataloguing in Publication record for this book is available from the British Library.

All work contributed to this book is new, previously-unpublished material. The views expressed in this book are those of the authors, but not necessarily of the publisher.

Chapter 12

Models for Interpretive Information Systems Research, Part 2: Design Research, Development Research, Design–Science Research, and Design–Based Research – A Meta–Study and Examples

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ABSTRACT

This chapter introduces interpretive research as a background to research that is time- and context-dependent. The study presents practical, yet theoretical research approaches that are relevant to postgraduate studies and to ad-hoc research. The models proposed as interpretive research designs are development research, design-science research, and design-based research. Systems development, in and of itself, is not research, but when integrated with evaluation and applied both to solve real-world problems and to propose general design principles, it gives rise to development research. Design research – termed design-science research in the domain of information systems (where it has roots in software engineering) and design-based research in educational technology (where the approaches are more pragmatic) – has clearly defined features and methods in each domain respectively. The common attributes are the generation of creative and innovative artifacts to serve in complex situations, and the joint advancement of theory and practice. The three research designs are described, and each is illustrated by an example of a study where the model was applied.

DOI: 10.4018/978-1-4666-0179-6.ch012

INTRODUCTION AND BACKGROUND

Interpretive research, which originated in the behavioural social sciences, is increasingly applied in Information Systems (IS). In line with the current emphasis within IS on the social dimensions of computing, researchers and practitioners are taking cognizance of human factors and behavioural aspects. This chapter forms Part 2 of a discourse on models for interpretive information systems research. It follows on Part 1, which is a separate chapter in the book, Chapter I.7a. This meta-research study is not aimed at major systems for business, but more at small-scale systems for personal computing, in particular user-centered educational software systems. It suggests various underlying theoretical models to guide the research and development process, providing cohesion and internal consistency.

For overviews of the positivist and interpretive research paradigms, qualitative and quantitative research methods, and relevant terminology, the reader is referred to Part 1 (Chapter I.7a). Part 1 discusses interpretive IS research, then describes and graphically illustrates two interpretive approaches: *action research* and *grounded theory*, explaining their operation as research designs and giving examples of situations where they were applied as the underlying research model. This chapter, Part 2, has a similar approach and structure, and presents three models from the family of design- and development research – *development research*, *design-science research* (so-called in IS), and *design-based research* (in the educational technology context). In three respective sections, descriptions are given of their features and processes, and examples are provided of studies where these research designs were applied.

We briefly re-visit some key concepts from Part 1. Research paradigms are based on varying philosophical foundations and conceptions of reality (Cohen, Manion & Morrison, 2005; du Poy & Gitlin, 1998; Olivier 2004). Each paradigm, in

turn, is implemented by associated methodological strategies.

The positivist paradigm holds that knowledge is absolute and objective, and that a single objective reality exists. Positivism is implemented by the scientific method, in which knowledge is discovered by controlled means, such as experiments and other quantitative methods based on numeric data and measurements. Results should be value-free, consistent, unbiased, and replicable.

Interpretivism, by contrast, aims to find new interpretations or underlying meanings and permits the accommodation of multiple correct approaches and findings, mediated by time, context and researcher. Inquiry is value-related, influenced by context and by researchers' subjective interpretations. Interpretivism is associated mainly with qualitative studies that address research questions relating to phenomena in naturalistic, human-based social settings. Data is mainly verbal and research is often triangulated by multiple methods of data collection.

Hybrid approaches, combining interpretivism and positivism, are also used. Mixed-methods research capitalizes on applying both qualitative and quantitative methods, which are not mutually exclusive, although one is usually predominant, e.g., QUAL + quant (Creswell, 2009). Many studies require eclectic inquiry to cover the terrain and to apply methodological triangulation and data triangulation. Qualitative research can be exploratory, with its findings used to formulate hypotheses for subsequent quantitative analysis and verification. Conversely, the findings of quantitative studies can be tested and extended by using qualitative research, e.g., interviews, to enrich the data.

Research designs and paradigms used in Information Systems, are under the spotlight (Baskerville, 1999; Cockton, 2002; De Villiers, 2005; Glass, Ramesh & Vessey, 2004; Myers, 2004; Pather & Remenyi, 2004). Interpretive and evaluative approaches have become accepted (Klein & Myers, 1999; Roode, 2003; Walsham,

1995a; 1995b). Klein and Myers claim that interpretive studies provide deep insight and help the IS research community understand human thought and behavior in social and organizational contexts.

The present study suggests practical, yet theoretical, approaches, which are applicable to postgraduate studies, basic research, and *ad hoc*-research. Over and above technological and computational dimensions, attention is paid to human and contextual factors. The human-computer interaction (HCI) aims of generating usable, interactive, user-centric computing applications, are acknowledged and applied in domains beyond business systems, for example, systems for e-learning/e-training and for bridging the digital divide.

The next sections discuss and illustrate the selected models and their use as research designs. Each approach has associated methods and techniques and is illustrated by practical examples, some of which relate to research by the author, her colleagues, and postgraduate students.

DEVELOPMENT RESEARCH

Introduction to Design and Development Research

The family of design research and development research comprises various research models. Terminology varies, but the concepts of innovation, design, constructed artifacts and/or interventions are common characteristics. The variants considered are *development research* (an early term) and two forms: of *design research* (current term). In Information Systems (IS) and Information Technology (IT), design research is called *design-science research*, and in Educational Technology, the prevalent term is *design-based research*. Educational systems, i.e. e-learning applications, form a subset of IS at its intersection with the learning sciences, and are common topics for postgraduate studies.

Definition and Origins

Development research (DR) has a dual focus:

- It develops practical and innovative ways of *solving real problems*.
- It proposes general design principles to *inform future development decisions*.

A classic seminal publication by Nunamaker, Chen and Purdin (1991:89) sets the original foundations for DR, referring to ‘systems development as a research methodology’ and advocating a systems development research process, based on software engineering methods. Nunamaker *et al* point out that a developed system can serve both as a proof-of-concept of the research, and as a real artifact that becomes the object of further, extended research. They advocate an integrated and cyclic systems development approach to research, including theory building (conceptual frameworks and mathematical models); experimentation (simulations, fieldwork and lab experiments); and observation (case studies and surveys). The outcomes of this multi-methodological approach are prototypes, product development and, ultimately, transfer of technology, as the results contribute to the body of knowledge. The outcomes evolve due to performance testing and evaluative research. The subsequent DR approaches of Reeves (2000) and van den Akker (1999; 2002), which originated in educational technology research, aim for practical and scientific contributions, supporting graduate students and researchers in pursuing development goals after a tradition of research based on the scientific-method. DR is problem-oriented, searching for new and innovative solutions, while striving for findings that are transferable, practical, and socially responsible. The complex and dynamic relationship between theory and application is acknowledged, as DR guides practice by generating design principles and methods that are both theoretically underpinned and empirically tested.

Epistemology of DR

Development research has a pragmatic epistemology as it acknowledges collaborative shaping by researchers and practitioners. Describing the knowledge acquired from DR, Van den Akker (1999) distinguishes between substantive design principles, relating to characteristics of suitable *products* and methodological aspects, with a procedural emphasis for optimal development *processes*.

In formative research, knowledge is inductively extracted from the experience of using and evaluating a prototype developed for the study. This connects the two branches of the dual focus, namely the developing solution to a specific problem and the evolution of generalisable design principles. The experiential evidence obtained from iteratively studying a prototype in use, is enhanced when integrated with theoretical arguments.

Research Process and Methods

Development research generates different kinds of research questions. *Descriptive* questions examine the nature and extent of a problem, while *development* questions investigate an intervention or new product to address the need. A *principial* question aims for generalisable principles and guidelines for use in an application domain.

The process commences with the analysis, design and development of an artifact or intervention as a solution for a real-world problem. This, in and of itself, is not yet research. It becomes research when the design-and-develop project is conducted from the perspective of a researcher striving to understand issues of the application domain and its target users, such as the required characteristics of products and reasons for such. Research is based on iterative analysis, design, development, implementation and formative evaluation (ADDIE model of instructional technology), which feeds into redevelopment and improvement. Van den Akker (2002) terms the

process ‘successive approximation of the ideals’. Evaluations can be done by one or more usability evaluation methods, such as surveys among end users, observation, formal usability testing in a laboratory, logging, etc.

There are various models of DR. The approach used by van den Akker and his co-researcher, Plomp, (van den Akker, 1999; 2002) refers to outcomes of an intervention. *Immediate outcomes* relate to results of using an intervention or product within the cyclic process, and *distant outcomes* emerge when the immediate outcomes lead to generalisable principles. Reeves’ (2000) model emphasizes iterative interaction between researchers and practitioners to clarify the problems and refine potential solutions in a process of evolutionary prototyping and evaluation. Figure 1 is a generic DR representation. Its iterative phases can be effectively used to structure an IS research process, providing continuity and cohesion.

Application and Example

Many IS studies involve the generation of software artifacts or web applications. These vary from simple prototypes, through interactive web sites with backend databases, through to virtual reality simulations. Design, implementation and testing comprise the focus area of development but are not research. The introduction of evaluation, which entails more than testing of functionality, constitutes a meaningful contribution to the body of knowledge. As previously stated, dual-focused research producing both an effective solution and generalisable principles for the domain, further enriches the research.

A product – often a prototype – can be custom-built to solve a problem, then iteratively evaluated and refined. For example, Conradie and de Villiers (2004) of the School of Computing at the University of South Africa (UNISA) describe the design and evaluation of an educational software tool to solve a real-world assessment problem by electronically assessing open-ended textual input,

termed ‘free text’. Many Web-based learning environments tend to become repositories for course materials and students’ deliverables. There is a lack of interactive, dynamic pages that respond diagnostically to their academic contributions. The situation is mitigated by Web 2.0 technologies and online discussion forums but, in general, educational WWW environments present multi-media content and share information, but fall short in assessment. Most electronic assessment is in the form of multiple-choice testing. Conradie set out to address the need and improve the effectiveness of e-learning by developing, implementing, testing and analysing a prototype tool for automated assessment of textual inputs.

The tool used keyword searches and pattern-matching techniques (not artificial intelligence) to assign grades to short-answer free-text responses on course content. In line with the iterations in Figure 1, two variants of the prototype were designed and used as interventions with third-year Computer Science students. The first variant demonstrated feasibility of the e-assessment, while the second was an interactive web-based extension, the *CyberClassroom*, which provided interactive support by supplementing the scoring mechanism with instant feedback (related to the input) and animations and by recording scores. Students participated in evaluation, giving qualitative evaluation data in different ways – posting messages on the *CyberClassroom*’s notice board

and communicating directly with the instructor-developer. Further empirical evaluation compared the scores with those of manual grading by an expert human assessor. Following evaluation and identification of problems and usability issues in the prototype, the intervention was refined. Use of the electronic tool achieved dual outcomes: an immediate outcome by reducing the tedious processes of manual marking (grading) and recording results for a course in the BSc programme; and it also provided a generic system for cross-domain application, since it could be exported, context-free, to databases containing questions, solution patterns and grading algorithms for other content.

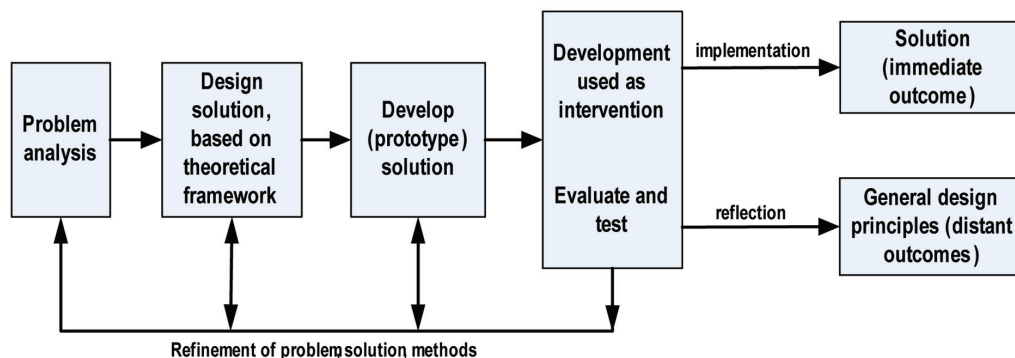
As well as being used for research and development for software solutions, DR which is relevant to computer science and engineering, can be used to generate hardware solutions and associated generic principles.

DESIGN-SCIENCE RESEARCH IN INFORMATION SYSTEMS

The first few paragraphs serve as an introduction to both design-science research and design-based research.

Design research is increasingly undertaken in disciplines such as information systems, the learning sciences, and educational technology. Due to differences between the ways it is applied

Figure 1. Development research model (synthesized by de Villiers, 2005; influenced by Reeves, 2000)



in different areas, terminologies, methodologies, and practices vary. For this reason, the so-called *design-science research* in information systems (IS) and information technology (IT) is treated separately from the *design-based research* of educational technology (ET).

Definition and Origins

Design research owes its origin to the Nobel laureate, Herbert Simon (Simon, 1981), who distinguishes between the *natural sciences* and the so-called *design sciences*. Natural sciences relate to natural phenomena such as those described in physics, astronomy, anatomy, etc. Associated descriptive theories explain how phenomena occur, discovering underlying laws and relationships. Design sciences, by contrast, are ‘sciences of the artificial’ and relate to man-made objects and artificial phenomena, generated in applied sciences such as medical technology, engineering, architecture, product design, and instruction. Associated prescriptive theories and models set out goals to be achieved and procedures to accomplish ends. For Simon, design science achieves its potential when innovative artifacts are created that solve real-world problems. Applied design sciences are characterized by problem-solving processes, invention, and the construction and evaluation of artifacts or interventions. Design science led, in turn, to design research, which:

- In information systems (IS) and IT, is called *design-science research* (DSR) and relates mainly, but not exclusively, to business artifacts. It is discussed in this section.
- In educational technology and e-learning, is termed *design-based research* (DBR) and is discussed in the next section.

DSR and DBR are not primarily development models. Instead, they model the research involved in the design and development of innovative prod-

ucts and environments, particularly in complex domains.

This section overviews the general IS approach of design-science research (DSR). The literature relates more to ISs in the workplace than to personal computing. According to the *Design Research in Information Systems Group* (Design Research in Information Systems (DRIS), 2006), design research changes the state of the world by introducing novel, performance-improving artifacts. DSR is a problem-solving activity involving invention, evaluation, measurement of artifacts, and investigation of their impact. Hevner, March, Park & Ram (2004) describe design science research as a problem-solving approach, rooted in engineering and Simon’s sciences of the artificial. DSR aims to create innovative and effective technological artifacts as solutions to problems in ill-defined environments characterized by complex interactions and flexibility. Human cognition, creativity and teamwork are required to generate solutions. Existing foundational and methodological knowledge help to achieve rigour but, where there is no pre-existing knowledge base, designers use intuition, experience, and even trial-and-error. Prototypes are particularly valuable for proof-of-concept purposes.

Epistemology of DSR

Design research changes real-world states by introducing novel artifacts. In contrast to positivist ontologies, it acknowledges multiple world states, but does not view these states as identical to the multiple realities of interpretivism. DRIS (2006) suggests that DSR is neither positivist nor interpretive research, but in between as a philosophical perspective with a pragmatic, problem-solving approach that tolerates ambiguity. DSR has aspects of interpretivism, since its cycles of observation and interventions are similar to action research, but with shorter time frames.

The basis of DSR’s knowledge claims can be termed ‘knowing-through-making’. Hevner *et al*

(2004) explain that knowledge emanating from DSR is obtained via construction in context, and its meaning is iteratively revealed through cyclic study of the constructed object.

Research Process and Methods

Design has double connotations. As a verb, it relates to processes and, as a noun, to products. When design research is applied to classic ISs (business applications in organizations), its outputs are not only the complete systems, but also their building blocks. March and Smith (1995) and Hevner, March, Park and Ram (2004) describe the artifacts and activities of DSR. The output artifacts of DSR are not restricted to functional computing systems. Rather, they are defined as constructs, models, methods and instantiations: *Constructs* or *concepts* are the domain vocabulary that describe problems and specify solutions. They may be formal notations for data modeling or informal text. *Models* are forms or representations where constructs are combined to show relationships, e.g. entity-relationship diagrams. Models are useful in the process of designing an application. *Methods* are ways of performing goal-directed activities, often involving a set of steps, e.g. an algorithm. They build on constructs and models in the problem-solving process of systems analysis and development. An *instantiation* is an actual implementation that performs a task in a particular environment. It may be an IS itself, a prototype, or a tool for designing ISs. Instantiations are the final link in the research chain, as they operationalise constructs, models and methods. Citing Rossi & Sein (2003) and Purao (2002), DRIS (2006) suggested a fifth output, construction of *better theory*. Theories emerge as methods are studied and as construction and evaluation elaborate existing theories.

The two main complementary activities in generating DSR outputs are building and evaluation (March & Smith, 1995; Hevner, March, Park, & Ram, 2004). Constructs, models, methods, and

instantiations are *designed and built* to meet identified needs within the user community, usually a business context. Foundational knowledge is required for building theories, frameworks and tools from prior research, although when completely new artifacts are created, they are experimental, and often done with little prior knowledge. *Evaluation* determines how well the artifacts function in their environments and feeds back into building. Criteria and metrics are established to judge performance in context or to compare versions. IS evaluation uses mathematical modeling and computational techniques, as well as empirical and qualitative methods to identify problems and strengths. Efficiency, effectiveness, and impact on environment should be considered, as well as human issues as subjects interact with artifacts in context, which requires qualitative study.

DRIS describes design research as: awareness of problem; suggestion of new, creative functionality in an area of complexity; design and development of an artifact with novelty in the design; evaluation feeding an iterative loop back to design and development; concluding the research with a 'satisficing' end, which means finding satisfactory solutions while sacrificing an exhaustive search through all possibilities.

The artifacts and activities are combined in the *Information technology design-research framework* (March & Smith, 1995), which maps the activities of building and evaluation against the four artifacts: constructs, models, methods, and instantiations. Hevner *et al* (2004) extended the framework, presenting a comprehensive *Information systems research framework* in the context of Simon's (1981) problem space containing organizations, people, and technology. This integrated framework shows the contributions of design research and behavioural research to IS research. Hevner *et al* also compiled guidelines for design-science research in IS:

- i. **Design:** An innovative, viable artifact must be designed and produced (construct, model,

- method, or instantiation) to address a particular organisational problem. The artifact is unlikely to be a full-scale operational product for use in practice.
- ii. **Relevance:** A technology-based solution must have utility in addressing the problem.
 - iii. **Evaluation:** Utility, quality and efficacy must be demonstrated by appropriate evaluation methods. Integration of the artifact into its environment should be investigated. Evaluation methods include observational, analytical, experimental, testing, and descriptive techniques.
 - iv. **Research contributions:** These should be clear and verifiable in terms of the artifact's design foundations, as well as new, innovative and interesting.
 - v. **Rigour:** Rigorous methods should be used in construction and evaluation, but rigour should not reduce relevance in the application domains. Metrics should be related to the evaluation criteria. Furthermore, the human aspects should be addressed appropriately.
 - vi. **Design as a search process:** Suitable methods are iteration, heuristic search, and generate-and-test cycles. The problem can initially be simplified and decomposed, followed by expansion, i.e. a 'satisficing' approach.
 - vii. **Communication:** Results should be presented both to technological and user-oriented audiences. The former require construction and evaluation details, while the latter are concerned about the impact, novelty and effectiveness of the artifact.

Finally, Hevner and Chatterjee (2010) acknowledge that the progress of design research in IS has not been rapid.

Application and Example

Artifacts generated by DSR are not restricted to the design of full computing systems; the artifacts

can be models, methods, and instantiations. The example that follows, relates to a model and methods for a procedure in the HCI subdiscipline of IS, namely procedures for formal usability testing of interactive e-learning systems (Masemola and de Villiers, 2006). Research has been conducted at UNISA's School of Computing to generate frameworks and methods for usability testing of e-learning applications for teaching, learning, and hands-on practicing of cognitive subject matter.

Usability testing (UT) data is obtained from real-time monitoring, logging, video and audio recordings, as well as eye-tracking. Procedures for controlled evaluation of conventional task-based information processing systems in usability laboratories are well established. The usual goal of UT is to identify problems in conventional software interfaces by measuring participants' performance in terms of: time spent, errors made, recall, and subjective response. The present example, by contrast, investigates interaction with CD-based e-learning tutorials for teaching and learning theoretical computer science. As well as applying performance metrics that test the interface and interaction design (Preece, Rogers & Sharp, 2007), the actual learning of cognitive content and the associated computational skills must be studied. The approach differs from conventional usability testing, since the distinctive characteristics of human perception and learning processes require a different framework. Differences occur in terms of:

Time spent: Efficiency cannot be judged by low times spent on learning tasks. Users have different learning styles and approaches.

View of errors: It is not always desirable to minimise errors. Usability errors should be considered as errors, but cognitive errors can be viewed as learning activities.

What is investigated: Use of the learning content is analysed, as well as interaction at the interface.

This pioneering research contributes to a generic UT framework and metrics for investigating

e-learning applications and human learning behaviours, as the researchers used the sophisticated technology of a controlled usability lab in novel and interesting ways to study students' actual learning experiences with e-learning tutorials. This is in line with DSR's aim of creating innovative technological artifacts to address problems in ill-defined environments characterized by complex interactions. Masemola and de Villiers (2006) developed an initial model, a set of methods, processes, measurements and documents for investigating UT of interactive e-learning applications. To achieve rigour and to base the methodology and test plan on accepted methodological knowledge, HCI literature was studied. Features relating to learning behaviour and cognitive processing were also incorporated. Participants were actual students, who were requested to verbalise out loud as they did the specified learning tasks, expressing their expectations, reasoning, and interpretations. By recording 'think out loud' protocols over and above visual observation, the monitoring technology provides added value, informing researchers how learners use their time when apparently not engaged in active interaction, or doing exercises. It distinguishes between time spent on the interfaces and navigation, and time spent on cognitive activities as learners engage with the instructional content. The different types of errors made, were of great significance in the framework. Furthermore, a best-case scenario was acquired for benchmarking learner performance.

This research continued as Adebesin, de Villiers and Ssemugabi (2009) refined and modified the model and methodologies. The initial study had showed that think aloud was unnatural for some participants and distracted them from learning. In the follow-up study, verbalisation was combined with co-discovery to address this reticence. Participants were paired and tackled tasks collaboratively. Conversation and peer teaching occurred naturally and they were less inhibited about expressing opinions. Co-discovery also identified causes of learning problems. Re-

search is ongoing, extending the methodology by qualitative investigation of types of errors. In this regard, De Villiers (2009) presented early work on analysis of usability errors and cognitive errors as a pilot study for the in-depth research currently underway. Since 2008, the research has been triangulated with eye tracking studies, increasing the validity and reliability of the studies. To repeat, the artifact undergoing DSR is not the e-learning system being evaluated; rather, it is *the methodological model* for usability testing of interactive e-learning in cognitive domains. In line with DSR principles, the research provides pragmatic findings and shows how the evolving artifact functions in contributing to knowledge about learning with technology. Synergistically, the model proposes generic methodological approaches for usability testing in the domain of interactive e-learning.

Findings are presented to research communities, achieving the DSR requirement that results should be communicated both to technological and user-oriented audiences.

DESIGN-BASED RESEARCH IN EDUCATIONAL TECHNOLOGY

The first few paragraphs of the preceding section on design research and design science, also serve as an introduction to this section.

Design research is also undertaken in the learning sciences and educational technology (ET), where the prevailing term is *design-based research* (DBR). It is a maturing extension of DR and is increasingly used as the model for studies on *development of e-learning materials* and environments. It is widely discussed in current literature, involving meta-analyses as well as reported research.

DBR is a paradigm for educational inquiry where the goal of using technology to solve problems and design learning environments in complex ill-structured situations, is related

to the goal of developing prototypical theories (Design-Based Research Collective, 2003; Wang & Hannafin, 2005). With regard to the first goal, the success or failure of a design in its setting should be documented and explained. With reference to the second, research should result in contextually-sensitive, sharable design theories, communicated to practitioners and designers. The process by which this occurs is development and research through continuous cycles of analysis, design, development, enactment, evaluation, and redesign. Amiel and Reeves (2008) argue that technology itself should be viewed not as an artifact, but as a process, producing a continuous cycle of design-reflection-design.

Definition and Origins

Design science relates to man-made objects/phenomena, including instruction with its prescriptive theories and procedures. Education is characterized by complex problems, which are addressed by the invention of solutions, and the construction and evaluation of artifacts. It is a suitable domain for the application of design-based research as a paradigm for educational inquiry. The terminology evolved from the 'design experiments' of educational practice conducted by Brown (1992) and Collins (1992) through 'development research' (Reeves, 2000; van den Akker, 1999), as addressed earlier in this chapter, and consolidated at 'design-based research'. To clarify terminology, Wang and Hannafin (2005:7) compiled a useful table of terms and methods.

Barab and Squire (2004) define design-based research as a series of approaches which aim to produce new theories, artifacts, and practices related to teaching/learning in natural settings. In the specific context of ET, DBR is characterized by:

- *Pragmatic and theoretical approaches*: generating and extending prototypical theories; producing principles to inform and improve practice.

- *Grounding*: design of learning environments in real-world settings, based on appropriate learning/instructional theories.
- *Problem-focused ethos*: addressing complex problems in real contexts.
- *Interactivity, iteration and flexibility*: designer-researcher-practitioner-participant teamwork; continuous cycles of analysis, design, prototypes, development, enactment, formative evaluation, and usability analysis; and revision and improved-design.
- *Transparent communication*: research should result in contextually-sensitive, sharable design theories, communicated to practitioners and designers.
- *Integration*: hybrid research methods; data from multiple sources; integration of design principles with new technologies to solve complex problems.
- *Rigorous and reflective inquiry*: testing and refining innovative e-learning environments and defining new design principles.
- *Contextualisation*: success or failure of a design should be documented with relation to its setting.
- *Extension of existing methodologies*: such as action research, which sets out to change situations.
(Wang and Hannafin, 2005; Design-Based Research Collective, 2003; Reeves, 2006)

Epistemology and Ethos of DBR

Reeves (2000) cites Stokes' (1997) call for use-inspired basic research, where new knowledge advances new types of research, producing a reverse model that moves from applied research to basic research. The experimental generation of new prototypes highlights the roles of cognition, intuition, creativity and teamwork in solving problems and generating knowledge. The philosophical foundation of DBR is not positivism, but pragmatic enquiry, where judgement is based on

the ability of a theory to work in the real world (Barab & Squire, 2004). Evidence-based claims demonstrate that a particular design works, relating it to contemporary theoretical issues. This enquiry occurs in naturalistic settings, rather than laboratory environments, as knowledge about artifacts such as e-learning systems evolves in context, and even by trial and error. Contextual investigations lead to a minimal ontology, in that researchers cannot return to the laboratory to test their claims further. Moreover, the research is not replicable due to the role of context.

Validation occurs when results regarding the designed object are validated by actual use. Validity in DBR can be achieved by iteration, as the iterative evaluation processes confirm findings and align theory, design and practice (Design-Based Research Collective, 2003).

Dede (2005:6) expresses concerns about combining designs from the 'skills of creative designers' and research by 'rigorous scholars'. When *designers* have free reign, there may be 'design creep' as exploratory sweeping interventions evolve into full-scale initiatives instead of being bounded research. A technological innovator might champion a particular technological solutions and search for situations in which to apply it. Pure *researchers* have contrasting weaknesses, aiming for designs where the variables are suitable for straightforward data collection and analysis. Some such scholars have 'design constipation' (Dede, 2005:6), as they apply analytic and methodological frameworks at the expense of effective, scalable and sustainable innovations.

Kelly (2003), by contrast, lauds DBR's convergence of research and design. First, it is innovative and acknowledges the expertise of true designers. It plays an exploratory role in novel environments, where it addresses relevant research questions, yet solves problems in pragmatic ways. Second, it contributes to contextualised theory development as well as the advancement of cumulative design knowledge. Kelly's third point is that DBR fosters cross-disciplinary exchange of expertise

and leads to insights when interventions occur in so-called 'messy' settings. In complex and ill-structured environments with real-world messiness, the design of artifacts and the development of appropriate theories proceed concurrently, each mutually informing the other.

Design research in e-learning has different methodologies and frameworks from the design research of pure IS with its software engineering roots (previous section). DBR research has methodologies and frameworks based on a strong interpretive paradigm, qualitative studies and mixed methods (Creswell, 2009). This contrasts with its traditional positivist stances and quantitative studies.

Research Process and Methods

The advent of design research in applied computing disciplines, such as information and communication technology in e-learning, owes much to design experiments, which occurred not only in the context of educational technology, but also in the general learning sciences, where 'design' may refer to the design of experiments or learning configurations, not just to the design of artifacts. Brown (1992) engineered innovative educational environments and did experimental studies in natural settings, teaching children to read, self-reflect, and retain content. The dual goal was to inform practice and work towards theoretical models. Collins (1992) conducted design experiments on educational technology in the classroom, investigating, evaluating and comparing the use of various technologies and computing tools for learning about geographical phenomena. The idea was to construct a systematic methodology, a design science of education, to support educators in exploring the problem space of designs for teaching and learning with technology.

Collins, Joseph and Bielaczyc (2004), using the term 'design research', reflectively outline the emerging theoretical and methodological issues. Generic research findings are required, but the

fundamental emphasis is on studying learning in context and using methods that situate research in real-world settings, not in controlled laboratories. Real-world classroom situations present challenges due to the lack of control and large amounts of data from triangulated ethnographic and quantitative studies (Collins *et al*, 2004). Studies should be managed with systematic adjustments, so that each adaptation provides further experimentation. Collins *et al* also raise the issue that an implemented design may differ from the intended design. This is in line with ‘incorporated subversion’ (Squires, 1999), where users configure, or subvert, an environment or system to their own needs and use it in ways not intended by the original designer. This can have positive or negative repercussions.

Barab and Squire’s (2004) view highlights the generation and testing of theories to support understanding and prediction of learning, along

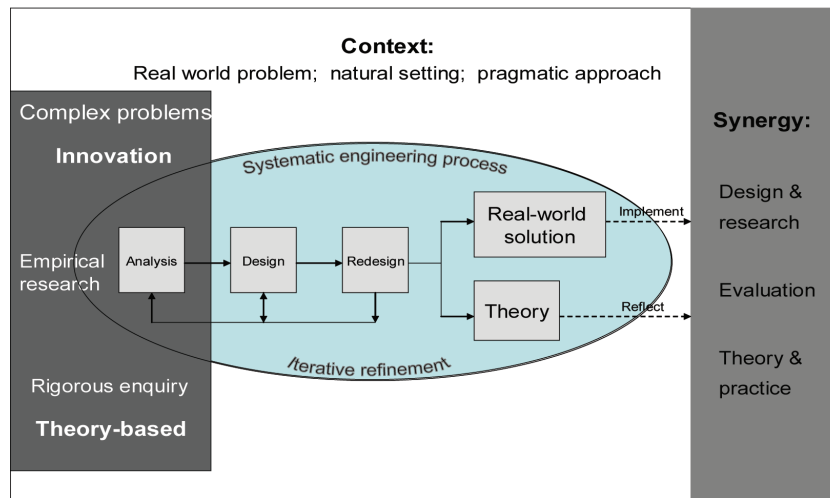
with the development of technological tools. Other research methods also generate theory, but DBR’s defining features are its goals of influencing practice with real changes at local level and developing tangible applications with the potential for adoption elsewhere. However, Barab and Squire express a word of caution regarding the transfer of context-specific research claims to inform broad practice.

DBR features have been extracted from the extensive meta-analyses and reflective studies of Amiel and Reeves (2008), Barab and Squire (2004), Cobb, Confrey, diSessa, Lehrer, and Schauble (2003), the Design-Based Research Collective (2003), Kelly (2003) and Wang and Hannafin (2005). The present author synthesized and classified them into Table 1, which summarises the main features of DBR in e-learning systems.

Table 1. Summary of features of design-based research models (synthesized by the author)

Features of DBR models	Elaboration
Real-world complex problems	Design theory addresses complex problems in collaboration with practitioners/educators.
Problem solutions grounded in pre-existing theories	Where appropriate theories/principles pre-exist, design should be theory-driven, along with technological affordances, to propose solutions to the problems. In non-standard cases, novel pragmatic solutions are sought.
Innovation	Underlying innovative approach: DBR should investigate less-common practices and generate technological support; design of innovations, novelty, and interventionist approaches.
Engineering	Systematic methodology that involves designing and studying means or artifacts of learning.
Iterative design	Cycles of design, enactment, analysis, redesign.
Context	Research studies in context, i.e. in naturalistic settings; use of artifacts/interventions in the real-world; theories also to be contextualized; responsive to emergent features of the setting (Kelly, 2003).
Empirical research	Studying tangible, real-world products, which ideally, should be usable elsewhere, i.e. influence on teaching, learning and training practice.
Refining the artifact /system	Using formative evaluation to derive research findings; design and explore artifacts, environments, etc. to refine them and define new design principles.
Output products: 1. Useful real-world products 2. Development of theory	Real-world products: technical and methodological tools; frameworks; interventions; even curricula. These offer immediate value in the environment of use. Theories that are generated, evaluated and refined in a reflective cycle: they provide a set of theoretical constructs that be transferred and adapted beyond the initial environment.
Pragmatic	The theories developed should do real work and be supported by evidence-based claims.
Synergy	Design and research are advanced concurrently. Theory and practice are advanced concurrently.
Rigorous and reflective inquiry	To test and refine innovative learning environments and to define new design principles.

Figure 2. Model of design-based research (synthesized by the author)



The present author adds that evaluation should consider human-factors, such as learner-centricity and the usability of artifacts.

Figure 2 complements Table 1 by depicting the concepts and processes of DBR. The central model represents its predecessor, development research (Figure 1) with its iterations and evaluative feedback loops. The surrounding infrastructure, which represents the context of real-world settings with complex problems, indicates DBR's evolution. The left side shows the approaches of innovation, rigorous empirical research, and a theoretical basis. The right side lists synergistic consequences of the reflective processes, as design and research are advanced jointly impacting on practice and on theory.

Application and Example

DBR is an approach for generating technological tools and e-learning environments in the complex intersection of learning and technology. In a bold venture, the Digital Doorway (DD) Project of the Meraka Institute at the Council for Scientific and Industrial Research (CSIR) in South Africa installed rugged computer terminals in schools, colleges and public community facilities in low-

income areas (Gush, De Villiers, Smith, & Cambridge, 2011). DDs offer unassisted learning and peer-teaching of basic computer skills, as well as the use of software applications ranging from entertainment, through education and information, to reference systems for research. The DD product and processes illustrate DBR in action, implementing many of the concepts and processes in Table 1 and Figure 2, as design and research, and theory and practice; are advanced concurrently in a real-world situation of complexity, where low-income, technologically-disadvantaged communities live beyond the digital divide. Infrastructure is lacking and, in many cases, not even school teachers are computer literate.

Following the success of the *Hole-in-the-Wall* experiment in India, which offered minimally invasive education and unassisted learning at computer terminals, DDs were implemented as a pragmatic and innovative solution to an African problem. Open-source software is used; usage is free and available to the entire community, although secondary school students are the greatest user group. Learning is motivated by children's natural curiosity and cooperative approach, both of which are evidenced in use of DDs. This ICT for Development (ICT4D) venture is customized to

the context. Since most DD terminals are located in easily accessible public venues, their rugged and robust, vandal-proof computer housing contrasts with typical lab-based computers. Lively, often noisy, social interaction occurs alongside learning activities.

Since the project commenced in 2002, iterative development and evaluation have occurred. The project has synergistic deployment and research phases, mutually feeding into each other. Empirical research employs various research- and data gathering methods. In an engineering approach, tracking tools record usage and collect quantita-

tive data by automated on-site logging (Gush & de Villiers, 2010). Subjective qualitative data is accumulated via interviews, observation and video of user interaction, and surveys. Rigorous and reflective enquiry has led to refinements and enhancements. From an initial single prototype, the hardware housing evolved to a multi-terminal configuration, and rollouts have occurred at over 200 sites. Poor electricity supply at some sites has led to solar-powered systems. A version has been produced for disabled users. Software is upgraded and content has been increased to better meet the needs of the users. Certain games, edutainment,

Table 2. Summary of the three models and their use as research designs

Properties	Development research (DR)	Design Research	
		Design sciences are ‘sciences of the artificial’, relating to man-made artifacts (Simon, 1981). Design science gave rise to design research.	
		Design-science research (DSR)	Design-based research (DBR)
Goals	1) Development of practical and innovative solutions to real-world problems (immediate outcomes). 2) Transferable and generalisable design principles to inform future decisions (distant outcomes).	1) Introduction of novel artifacts to enhance performance. Problem-solving via invention, evaluation, measurement, and impact studies. 2) Theories emerge; existing theories are elaborated.	1) Implementation of novel educational technology solutions in complex situations. New products and practices in real-world settings. 2) Development/extension of models and contextual design theories, shared with practitioners and designers.
All three have a dual focus: developing products and contributing to the body of knowledge.			
Distinct features	Pragmatic epistemology, based on collaboration between researchers and practitioners. Problem-solving orientation. Acknowledges complex and dynamic relationship between theory, principles, practice and application.	Rooted in engineering. Use of novel artifacts to change real-world states. Solutions generated by human cognition, creativity and teamwork in ill-defined, complex areas. ‘Satisficing’ findings, obtaining satisfactory solutions but sacrificing exhaustive search.	Rigorous and reflective inquiry into real problems in education or training Contextually-sensitive. Design experiments to find both practical outputs (innovative designs and prototypes) and theoretical outputs (contextualized theories)
Processes	Integrated and iterative analysis, design, development, implementation and evaluation processes. Problems clarified and solutions refined during the above processes. The developed system serves as proof-of-concept.	‘Design’ relating to both products and processes. <i>Products</i> : complete systems and building blocks, i.e. constructs, models, methods and instantiations. <i>Processes</i> : complementary activities of construction-in-context and cyclic evaluation studies, involving mathematical modeling and empirical studies.	Convergence of research, design and feedback. Continuous cycles of analysis, design, development, enactment, evaluation and redesign. Pragmatic inquiry, evidence-based claims, validation by use. Multi-disciplinary expertise. Interpretive paradigm, qualitative studies and mixed methods.
All three have iterative/cyclic design processes			
Application	Information systems (origin); Educational technology	Information Systems	Educational Technology / e-Learning

and information packages have been uniquely developed for the South African context. With further improvements in view, current studies are investigating usability issues and content usage.

Participants can be collaborators, as a feedback mechanism gives them the opportunity to type in comments and requests, which have contributed to extensions to DD features. Community leaders and other stakeholders have joined Meraka researchers at workshops on implementation and usage aspects.

Finally, there are dual output products: the useful real-world systems which have contributed to basic ICT literacy and, second, to the development of theories regarding effective and ineffective systems, deployment strategies, and the design of technology for rural contexts. Knowledge obtained from the systems is transferable to similar installations elsewhere.

CONCLUSION

Table 2 summarises the main features of the three research designs discussed in this chapter, namely: development research, design-science research (so termed in the discipline of information systems) and design-based research (term used in educational technology). The table shows the similarities and common origins of the models, yet highlights their distinctive features.

This chapter comprised Part 2 of a study of models for interpretive information systems research. The three research designs considered – development research, design-science research, and design-based research – were influenced by design science and the associated design research. They all have undergirding theoretical frameworks and processes, as well as repertoires of methodological and reflective strategies to model and guide a cohesive research process. Outcomes are the production of effective artifacts with real-world utility and transferability to other settings.

NOTE

An earlier version of part of this chapter appeared as an article “Interpretive Research Models for Informatics: Action Research, Grounded Theory, and the Family of Design- and Development Research”, *Alternation* 12,2 (2005): 10 - 52, and is re-used here with the permission of the publisher, CSSALL (© 2005 by CSSALL, P.O. Box 1734, Wandsbeck, Durban 3631, RSA). All rights reserved. The present version is based on a reduced form of the article in *Alternation*, augmented with new content.

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