Design-based research – the educational technology variant of design research: Illustrated by the design of an m-learning environment

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ABSTRACT

This paper, a meta-research study, focuses on design-based research (DBR), the educational technology variant of design science research (DSR). DBR is applied to develop and evaluate an m-learning environment, Mobile Learning Research (*m-LR*) delivered by mobile handheld devices. The emergence and evolution of DSR in the information systems discipline and, similarly, DBR in educational technology are overviewed, noting similarities and differences. The development of an m-learning application for a South African tertiary education context, illustrates DBR. The development and research process involved six iterations, comprising four evaluations and two digital profile studies. The study reflects on the nature and extent of the conformance of *m-LR* to the features and tenets of DBR. In line with the characteristic dual-outcomes of DBR, the development process not only generated the designed artifact, *m-LR,* but also produced theoretical contributions.

Categories and Subject Descriptors

H.5.2 [User Interfaces]: Evaluation/Methodology, Theory and Methods – *design science research, design-based research*

General Terms

Design, Performance, Theory

Keywords

Design-based research, Design science research, Design research, Educational technology, Evaluation, m-Learning, Tertiary education

1. INTRODUCTION

Design science research in the discipline of Information Systems (DSR or DSRIS) is on the increase, and is being applied in South Africa (SA) [27]. Similarly, design-based research (DBR) which is the educational technology variant of design research, is a paradigm of choice in e-learning, although it is not extensively used in South Africa. The focus of this study is to introduce and explain DBR and illustrate it with a South African application in the domain of m-learning.

The 2012 mobility survey reported by Arthur Goldstuck, managing director of World Wide Worx, suggests that patterns of mobile phone usage are changing in South Africa [10]. The use of mobile devices for voice communication is still prevalent, but usage of data is increasing in importance, especially among young users. Results indicate that 5% of respondents accessed the Internet by computer only, while 27% used mobile devices as their sole means of connecting to the Internet. A further 27% reported they accessed the Internet using both computers and mobile devices.

The phenomenon of mobile connectivity can be used as an advantage in education and training. The production of m-learning applications is a key issue for institutions that wish to support learning whilst learners are 'on the move'.

After an outline of the research design in Section 2, Section 3 introduces *design science* and *design research.* We overview *design science research* in Information Systems in Section 4 – its emergence and its evolution, then similarly overview those aspects of *design-based research* in Educational Technology in Section 5. To illustrate DBR, Section 6 presents the development of an m-learning application, *Mobile Learning Research (m-LR*), used in a South African tertiary learning context and delivered by mobile handheld devices. Section 7 revisits the goals of the study, and the paper concludes with Section 8.

2. RESEARCH DESIGN

The goals of the present study are to:

1. Present the principles and approaches of design science research and design-based research, and note similarities and differences between them.
2. Investigate the conformance of the development of *m-LR*, to the tenets of design-based research.

This work is a venture in meta-research, which is the study of research designs and research methodologies. Secondary data was obtained from extensive literature reviews conducted on (i) DSR as a research design in the disciplines of Information Systems (IS) and Information Technology (IT), and (ii) DBR in the domains of Educational Technology and e-Learning.

We then illustrate the DBR process by presenting selected aspects of a recent South African case where DBR was the theoretical framework used to create an application in the domain of mobile learning via handheld devices. The resulting artefact, *m-LR,* was an innovative environment,

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custom-designed by one of the authors in the context of teaching and learning at a tertiary institution. In line with the dual-outcome approach of DBR, *m-LR*'s development and evaluation process generated the designed artifact and also produced theoretical contributions.

3. DESIGN SCIENCE AND DESIGN RESEARCH

The winner of the 1978 Nobel Prize in Economics, Herbert Simon [33], distinguished between natural science and design science. Natural science is concerned with how things are, as it describes natural phenomena. Building on Simon, March and Smith [21] indicate that the natural sciences aim to understand reality and relationships, including traditional research in, for example, physics, biology, astronomy and sociology. *Descriptive* theories articulate these phenomena and their underlying laws and models. In contrast, *design sciences* are 'sciences of the artificial', relating to how things should be and to the creation of man-made objects in applied sciences such as engineering and architecture, and also in IT and education, the domains of interest in the present work. *Prescriptive* theories and models define procedures and formulae to achieve outcomes. Design scientists produce and apply knowledge of tasks and situations [21]. Simon [33] holds that design science (DS) achieves its potential when innovative artifacts are created that solve real-world problems.

Features of design science are problem-solving, invention, and the building and evaluation of authentic artifacts and interventions [8]. Design science led to *design research* (DR), which addresses real-world problems by generating and evaluating innovative artifacts to solve them. It is increasingly undertaken in computing and technological disciplines. Terminologies, methodologies and practices vary somewhat between disciplines. This paper addresses DSR in information systems (also termed DSRIS) separately from DBR in educational technology. DSR and DBR are not merely development models. Both have independent roots in Simon's design science and emphasize the research processes involved in the design and development of products and environments, particularly in complex domains and in context.

4. DESIGN SCIENCE RESEARCH IN INFORMATION SYSTEMS

As a pragmatic, problem-solving approach that acknowledges multiple states, the philosophical perspective of design research bridges positivist and interpretivist stances by incorporating various paradigms and research methods. DSR's cycles of observation and interventions are similar to action research. We first review certain seminal sources on DSR up to the mid-2000's, then consider more recent sources on its subsequent evolution.

4.1 The emergence of DSR in IS

With an invited paper in *Decision Support Systems*, March and Smith [21] were pioneers in DSRIS. In an IS milieu where quantitative and behavioural studies were predominant, they advocated IT research studies that (i) investigate artificial phenomena and (ii) deal with man-made creations. There are four types of DSR outputs, also termed artifacts [15; 21]: constructs, models, methods and instantiations. *Constructs* are the basic vocabulary and concepts of a domain. They may be formal notations for data modelling or informal text. When constructs are combined in higher-order constructions that show relationships, they become the second type, *models*, which represent tasks, situations, and artifacts. Models are useful in the process of designing an application. *Methods*, ways of performing goal-directed activities, are also designed and developed, involving a set of steps, e.g. an algorithm. DSR outputs are thus not restricted to operational computing systems. Only the fourth type, *instantiations*, involves actual implementations of products. They are the final link in the research chain, as they operationalise constructs, models and methods in given environments. An instantiation may be an information system, a prototype, or a technological tool.

The two main complementary activities in design science are building and evaluation [15; 21]. *Building* of constructs, models, methods, and instantiations, is done to meet needs of the user community, usually in a business context. Knowledge from prior research is required for building, although when completely new artifacts are created, they are experimental, and may be produced with little prior knowledge. *Evaluation* determines how well the artifacts function in their environments and feeds back into further building. Criteria and metrics are established to judge performance in context or to compare versions. Notably, March and Smith [21] propose that the evaluation criteria themselves must be designed to evaluate the artifact in a particular environment. The evaluations use various approaches: computational techniques, qualitative methods, and empirical studies to identify problems and strengths. Efficiency, effectiveness, and environmental impact should be considered, as well as human factors as subjects interact with artifacts in context. Design research suggests new and creative functionality in complex contexts; novel design and development of an artifact; and iterative evaluation to inform subsequent development [9].

We have mentioned four types of DSR outputs. The construction of better theory can be a fifth [9]. However, March and Smith [21] did not hold that theory was a DSR output, suggesting that theorizing and justifying, like building and evaluating, are research activities. To deal with theory, their *Design Science Research Framework* distinguishes between activities and outputs, and maps the *research activities*: build, evaluate, theorize and justify, against the *research outputs*: construct, model, method and instantiation.

Hevner, March, Park and Ram [15] extended this framework, to an integrated *Information Systems Research Framework* in the context of Simon's [33] problem space containing people, organizations and technology. Their framework shows the contributions of both design research and behavioural research to IS research. Hevner *et al.* also present seven guidelines for DSRIS practice:

1. Design: An innovative, viable artifact must be designed and produced to address an identified problem.
2. Relevance: The solution must have utility in addressing a relevant problem, though it need not be fully operational.
3. Evaluation: Appropriate evaluation methods, including observational, analytical, experimental, descriptive and testing techniques, must be employed to demonstrate utility, quality and efficacy in the artifact's context.
4. Research contributions: Should be clear, verifiable, new, innovative and interesting.
5. Rigour: Rigour is necessary, but should not reduce relevance. Metrics should be related to the evaluation criteria. Human aspects should also be addressed.
6. Design as a search process: Iterations and cycles of generate-and-test are appropriate design methods. The problem can be simplified and decomposed, followed by expansion, i.e. a 'satisficing' approach that seeks satisfactory solutions, while sacrificing exhaustive searches through all possibilities.

7. Communication: Results should be presented to end users and to professional or technological audiences. Users are interested in the artifact's impact, novelty and effectiveness, while technologists are concerned with construction details (list adapted from [15] and [8]).

4.2 Subsequent evolution of DSR

Eighteen years after Salvatore March [21] advocated design science research in IS and IT, it is on the increase and gaining maturity. Recent publications suggest new perspectives to support researchers and add value. In introducing the MISQ Special Issue on Design Science in IS, March and Storey [22] confirm that DSR is increasingly recognised as equal in stature to behavioural science research. They affirm that novel artifacts should be developed and presented; their utility must be rigorously evaluated; and the value they add to practice and to the body of knowledge, should be articulated and explained. Particularly notable is their stance in line with Hevner [15] that a DSR contribution should be characterised by identifying a relevant problem which had no adequate solution prior to the research.

Peffers, Tuunanen, Rothberger, and Chatterjee [29] suggest that an established DS research process model would encourage more IS research using the DS paradigm. Such a model, combined with prior DS research, would provide a complete design science research methodology (DSRM) and a set of activities. Using literature on design research and meta-level research about design research, they integrated the principles into a comprehensive methodology, a DSRM process comprising six activities in a defined sequence:

1. Identify and motivate the problem, capturing its complexity.
2. Define objectives for a solution (quantitative or qualitative); what it should realistically do.
3. Design and develop the artifact (a construct, model, method or instantiation). There must be a research component in the design.
4. Demonstrate use of the artifact to solve an instance of the problem (experiment, case study, proof, etc).
5. Evaluate: Use metrics and analysis to observe and measure to what extent the artifact solves the problem. If necessary, return to Activity 3 to improve the artifact.
6. Communicate: Publish in scholarly journals and professional vehicles.

Figure 1 depicts Peffers *et al's* DSRM Process Model [29], showing its six sequential activities. The process need not commence rigidly at Activity 1.

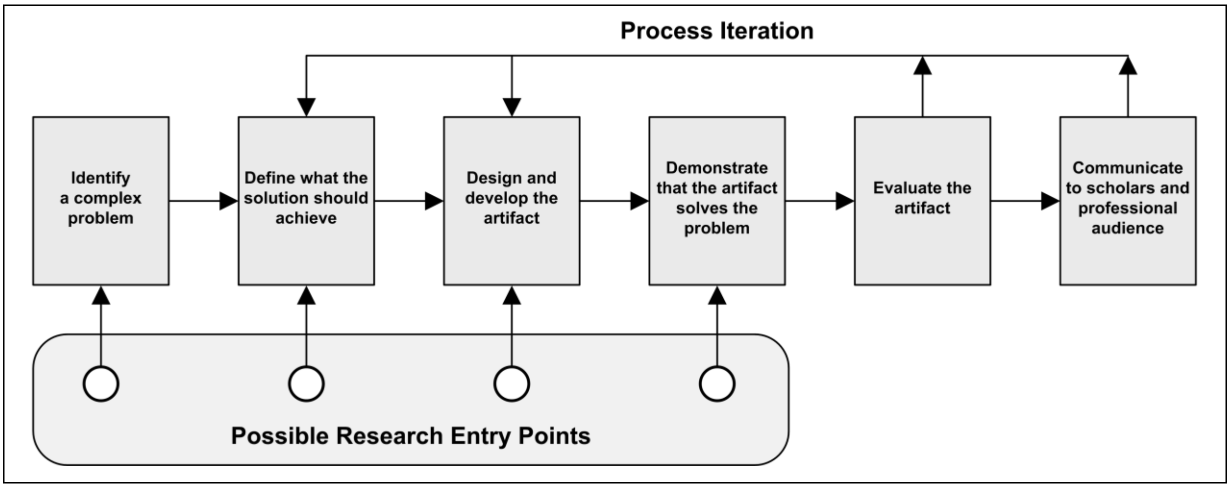

Figure 1: Generic Process Model for a Design Science Research Methodology (DSRM)

(adapted from Peffers *et al.* [29], with permission)

The role of theory remains a matter of debate. In an analysis of IS theory [12], Gregor defines design theory as a prescriptive theory for design and for action. In a 2013 publication, Gregor and Hevner [13] recognise two underlying issues that hinder DSR from having a stronger impact in IS.

First, there are divergent opinions on whether design theory should be an output of DSR and whether design knowledge is a legitimate theoretical contribution. If design theory is indeed an output, some scholars posit it should be emphasized more than the artifact outputs. There are two groupings: a pragmatic-design stance and a design-theory stance. Gregor and Hevner contend that the theoretical contribution need not necessarily be strong theory; it can be partial theory, an incomplete theory, or an interesting empirical phenomenon in the form of a design artifact. Regardless of the nature of the design theory, confusion occurs when it is explicitly viewed as an output artefact. To clarify matters, they restrict the term 'artifact' to viable artificially-made objects or processes that exist materially, in line with the four DSR products of March's seminal work, while a theory is more abstract. They advocate reconciling the inconsistencies by acknowledging both the concrete artifacts and abstract theories as contributions to knowledge [13].

Secondly, there should be better understanding of how DSR relates to the IS body of knowledge. In communicating their work, researchers should be able to position their outcomes and emphasize their most important contributions to the knowledge base. Publications could be based on a reporting pattern similar to a conventional research article, but replacing the results section with a description of the designed artifact [13]. The problem state should be interesting and the research should advance knowledge by solving the problem or by contributing to solutions. Furthermore, the methods should be new and transferable to other problems in the domain.

A variety of artefact types have emerged from DSR. In an analysis of 62 studies between 2006 and 2009, Offerman, Blom, Schőnherr and Bub [28] identified types of IT design and defined seven categories of artifacts: system design and implementations; method; language or notation; algorithm; guideline; requirements; pattern; and metric. Gregor and Hevner [13] mention widely ranging artifacts: decision support systems, modelling tools, management strategies, and IS interventions that support change.

5. DESIGN-BASED RESEARCH IN EDUCATIONAL TECHNOLOGY

This section overviews DBR in terms of its own tenets and terminology. We view Iivari's typology [16] to consider whether educational artifacts and e-learning systems are IS systems. The typology views IS 'as a design science that also builds IT artifacts' [16: p.43] and which includes seven archetypal IT applications based on their functions: processors – including transaction processing systems; tools (productivity systems); media and communication systems (e-mail, chat rooms, e-storage systems, etc); information sources; games, computer art, and digital pets. It is notable that e-learning systems and educational technology, with the functions of teaching and learning support, are not in this categorization. DSR literature does not appear to include such systems.

Instead, educational technology has its own design milieu, namely DBR and its own body of literature. The literature is less philosophical than DSR literature, as many of the publications discuss empirical studies and practical implementations of DBR in higher education or schools. Although DBR is pragmatic, it also emphasizes the production of theoretical and scientific outcomes. As we did with DSR, we first review foundational sources, then discuss more recent publications on its evolution.

5.1 The emergence of DBR in educational technology

Education involves man-made objects and artifacts such as technological interventions and designed curricula. Instruction and learning are characterized by complex problems that are addressed by inventing solutions and by construction and evaluation of artifacts. Design research is a suitable paradigm for inquiry in the learning sciences. The initial terms were 'design experiments' [6] and 'development research' [36]. Design experiments refer to experimental studies in natural settings and the design of learning configurations, as well as the creation of artifacts. Collins, Joseph and Bielaczyc [6] conducted design experiments, evaluating technologies and computing tools for learning geographical phenomena. The ultimate aim was to construct a systematic design science of education to support educators in exploring designs for teaching and learning with technology. *Design-based research* became the prevailing term and DBR is a now a discipline in its own right. Meta-analyses and artifact design are discussed in the literature and DBR is increasingly used as the research paradigm for developing educational technology and e-learning.

Barab and Squire [3] describe DBR as a series of approaches which aim to produce new theories, artifacts, and practices related to teaching/learning in natural settings, with the potential for adoption elsewhere. There are dual outcomes:

- A practical goal: to *solve complex real-world problems* in authentic situations by cycles of analysis, design, development, evaluation and redesign. Designs should be reported with relation to performance in their settings.
- A theoretical goal: to generate *contextually-sensitive, sharable design theories*, which should be communicated to practitioners and designers [34; 37].

The convergence of research and innovative practical design is affirmed [18; 37]. Artifact design, design knowledge, and contextualised theory development advance simultaneously, informing each other. DBR addresses relevant research questions, solves problems in pragmatic ways, and recognises the expertise of designers. It provides insight when interventions occur in ill-structured environments, with real-world 'messiness' [18]. The philosophical foundation of DBR is pragmatic enquiry, based on whether a theory can work in practice [3]. Evidence-based claims should relate designs to theoretical foundations. Enquiry occurs in natural settings, not in laboratories; knowledge evolves in context, even by trial and error. With a minimal ontology, researchers cannot go back to a lab to test claims, nor is the research replicable due to the role of context [3]. The designed object is validated by use. Validity is also achieved by iterative evaluations which affirm findings and align theory, design and practice [34]. The main features of DBR in Table 1 were synthesized from [3], [4], [34], [18], [37] and [8].

Table 1: Tenets and features of design-based research

Tenets and features of DBR
1. Real-world complex problems. Design theory addresses complex problems in collaboration with practitioners/educators.
2. Problem solutions Where suitable theories pre-exist, design should be influenced by theory, integrating design principles with new technologies. In the non-standard cases, seek novel, pragmatic solutions.
3. Innovation Underlying innovative approach: DBR should investigate less-common practices and generate technological support, aiming for design innovations, novelty, and interventionist approaches.
4. Context Studies in context, naturalistic settings: artifacts should have real-world use, be responsive to emergent features of the setting, theories contextualised; success/failure of design evaluated in its setting.
5. Systematic approach Systematic methodology for designing and studying artifacts or means of learning; products may be usable elsewhere.
6. Iteration Iterative cycles of analysis, design, prototypes, development, enactment, evaluation, analysis, redesign
7. Empirical research Study of tangible, authentic products in use; positive influence on teaching and learning practice.
8. Rigorous and reflective inquiry; refinement Design and explore artifacts. Formative evaluation to test and refine innovative learning environments and to define new design principles. Data from multiple sources. The present authors incorporate human-factors, such as learner-centricity, usability of artifacts, and user experience.
9. Communication and publication: Communicate contextual, sharable design theories and practices.
10. Pragmatic The theories developed should do real work and be supported by evidence-based claims.

11. Dual outcomes: **11.1** Useful real-world products: systems, interventions; technical and methodological tools; immediate value in context of use. **11.2** Development of theory: theories generated and refined in a reflective cycle, providing theoretical constructs that can be transferred and are adaptable beyond initial environment.
12. Synergy Design and research are advanced concurrently, each informing the other. Similarly, theory and practice advance concurrently.

5.2 Subsequent evolution of DBR

DBR has been applied since the early 2000's. Current publications reflect on it, raising questions and challenges.

The impact of computing tools on educational practice is being queried [1]. Has it been less than expected? Amiel and Reeves believe that the systematic and iterative methods of DBR can build stronger connections between educational research and real problems. Through cycles of design-reflection-design, both the innovative artifact and the emerging design principles can be tested and refined.

Mingfong, San and Ming [23] found that theoretical and practical challenges were hindering the design process of DBR projects. To transform the processes of learning with technologies, they propose aligning the following design components:

- The underlying frameworks for learning;
- Affordances of the instructional tools being used;
- Presentation of the required domain knowledge; and
- Contextual limitations, e.g. the culture and structure of the learning environment. These are often the dominant component, re-emphasising the role of context.

Fifteen years into DBR, it is relevant to know what types of studies have been reported. In a meta-analysis by Anderson and Shattuck [2], 47 highly-cited articles from 1940 DBR articles published between 2002 and 2011, were overviewed to establish whether DBR is living up to expectations. In particular, research results should make a difference in the practitioner's educational practice, as well as advancing theory. Of the 47 articles, 34% were philosophical expositions of DBR methodology and 66% were empirical studies, mainly using mixed methods, i.e. both quantitative and qualitative techniques. Papers originated in 11 countries, with 73% from the US. There were none from South Africa. Regarding the sectors of the study, 26% related to tertiary education. With regard to the subject or program, 51% addressed science education, 9% mathematics, and 7% computing education. Thirty eight per cent (38%) related to educational software or virtual environments, 14% to technology-supported learning activities, 14% to games and 10% to mobile learning. Twenty seven of the empirical studies were iterative and, of these, over half had progressed through three or more cycles. Of great interest is that only one article reported a study in its final stage!

Anderson and Shattuck argue that, as well as delivering real-world practical solutions by addressing immediate problems, DBR should stress the aspects of theory building and design principles, so as to improve research as well as practice.

Figure 2 presents a generic DBR Model showing the iterative design and research approach as a process in a natural context, progressing from the problem on the left to a solution on the right. The iterative and cyclic process model uses the notation of the classic ADDIE Model [24]: analyse, design, develop, implement, evaluate, and emphasises the need for rigour. The left side shows the initial complex problem and the need for innovation on which a pragmatic approach to the solution should be based, while the right side indicates the synergy that should result between practice and theory and between design and research.

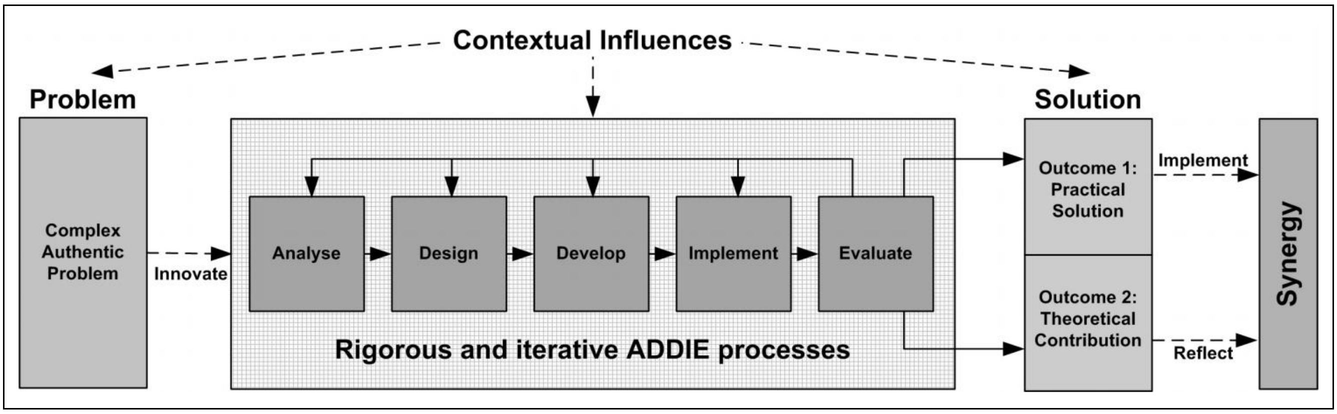

Figure 2: Generic Model of Design-Based Research Process within a Context [1; 3; 8; 24; 37]

6. AN ILLUSTRATION OF DBR: THE DEVELOPMENT OF *m-LR*

Mobile handheld devices, such as smartphones and tablets, are increasingly used for purposes other than telephony. The classroom is being augmented with m-learning applications for announcements, delivery of learning materials, quizzes and assessments, synchronous and asynchronous collaboration, academic social networking, online literature sources and digital media [20; 30]. Higher education learners interact with the Web in class-based situations and when opportunities occur to access the Internet via mobile phone in class, at home, or while travelling [19; 26; 32].

6.1 Learning with m-learning

The view of m-learning espoused in this study is that m-learning is learning achieved via a handheld digital device, such as a smartphone or tablet device, whilst the learner is on the move [5; 7; 17]. Georgiev, Georgieva and Smirkarov [11] suggest that m-learning is characterised by a large variety of mobile device types, including netbooks, tablet PCs, personal digital assistants (PDAs), mobile phones and smart phones. Their approach, however, focuses on the device as the mobile facet, disregarding the personal mobility of the learner while learning. Early attempts to define m-learning recognized it as a distinctive concept – spontaneous, situated, informal; and context-aware [35]. m-Learning environments should be adaptable and flexible. Academic content should be viewable in any sequence and the system should conform to ubiquity requirements, being usable anytime and anywhere [7]. The design should have a pragmatic user-centred focus. Traxler [35] posits that the practice of m-learning implies connectedness and personalised interactive learning.

Web-based learning (WBL) applications, accessed via the Internet, form the basis for m-learning systems, services and mobile device tools [31]. Mobile services are available to learners who are mobile and they combine mobile usability, wireless technology and an e-learning system [25].

6.2 DBR development and research process

This section presents the DBR development and research process of *m-LR*, which is a new supplementary learning tool for tertiary learners taking a 3rd year module in software engineering, taught by Researcher 2.

The real-world situation is first outlined. The learners were based on two campuses of the same institution. A complexity arose in that the composition of the student bodies was disparate due to varying socio-economic cultures. Students on one campus used public transport and many of them did not have access to a personal laptop, relying instead on mobile phones for multiple purposes.

Several of the students returned to homes in other countries for extended periods and used mobile devices for communication with the lecturer and collaborative projects with peers. Hence the need arose for a system such as *m-LR*, which was built on the Moodle™ platform and was intended for interaction via mobile handheld devices.

In line with DBR, *m-LR* evolved through various versions in its cycles of analysis, design, prototypes, development, enactment, evaluation, analysis and redesign. Details of this development process are given in Section 6.3.

Figure 3 illustrates the features offered by the later versions of *m-LR*, which included: communication with administrative and academic staff; collaboration with peers on group activities via discussion forums and chat rooms; access to online learning material in 'nugget' format'; downloadable course content and multimedia files; links to course-related websites, popular social networking sites and software engineering knowledge bases; interactive self-assessment quizzes for revision purposes; and a dictionary of software engineering terminology.

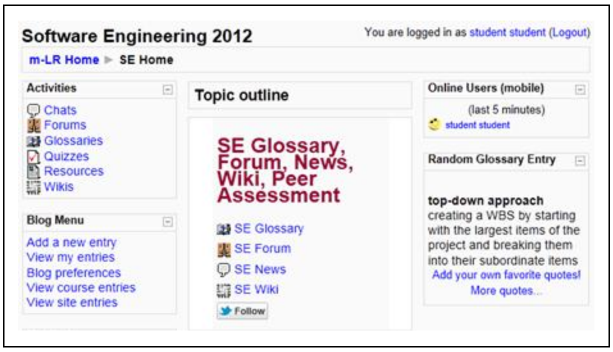

Figure 3: Screenshot of the home page for the Software Engineering 2012 module within *m-LR*

Figure 4 shows a linear representation of the iterative development process of *m-LR*, incorporating:

- Five versions of the *m-LR* implementation, namely: $m\text{-}LR_1$, $m\text{-}LR_2$, $m\text{-}LR_3$, $m\text{-}LR_4$ and $m\text{-}LR_X$;
- Four evaluation studies of *m-LR*;
- Two digital profile surveys to determine the type of devices used by the target group and the nature of usage.

The first four versions of *m-LR* constitute the *practical outcome* of the study. There was successive improvement in usability and functionality as feedback from evaluations led to reflection and redesign over two and a half years. Each of the four was implemented for a semester, while $m\text{-}LR_X$ to the right in Figure 4 is the future final and fully-functional application.

The iterative evaluation studies were fundamental to the DBR process, leading to successive refinement of *m-LR* as findings informed redesign and evolution. They also contributed to a *theoretical outcome* in the form of a custom-built evaluation framework. The evaluation methods were heuristic evaluation (HE) by expert evaluators and surveys among end-users (learners).

Finally, the digital profile studies provided insight into how the target group uses mobile technologies. Sections 6.3 and 6.4 describe the studies and their results.

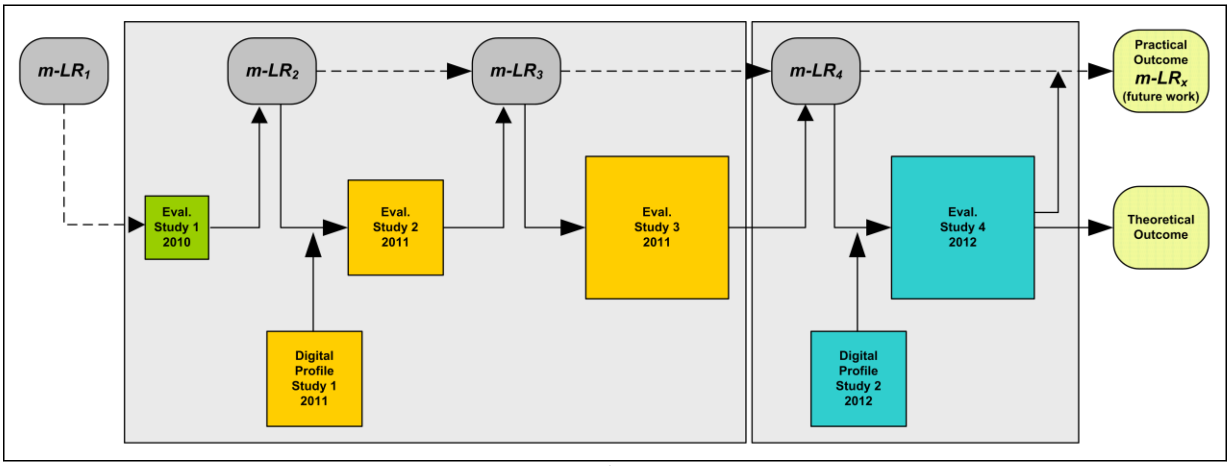

Figure 4: DBR development process of m-LR (synthesized by the researchers)

6.3 Evaluation studies

We briefly overview the four evaluation studies and the associated refinements to versions of *m-LR*. Full reporting on the evaluations is beyond the scope of this study.

Evaluation Study 1: *m-LR*$_1$ was evaluated by three expert evaluators in an HE and ten learners who participated in the questionnaire survey.

In *m-LR*$_1$, the first version of *m-LR*, course material was copied in and users had to scroll down to read content. It was delivered in an m-learning context via a BlackBerry 9700. Because it was designed on a Moodle platform, users could access the same WBL version from desktops, laptops and mobile devices.

Feedback from both groups of participants led to changes and extensions to *m-LR*$_1$, resulting in *m-LR*$_2$ with:

- A complete redesign of the look and feel of the interface;
- Redesign of the content to present short 'nuggets' rather than the scrolled textbook-style material. The chunked nuggets were more suited to delivery by mobile devices;
- Log-in facilities via a variety of devices;
- Reduction in the amount of information on a single frame, yet easier navigation to multiple pages;
- Inclusion of course content in various downloadable formats such as MS Word, PDF, slide shows, and video;
- Extension of academic content, increasing the glossary feature to make provision for additional terminology.

Evaluation Study 2: This was an evaluation of *m-LR*$_2$ in the form of a pilot, laying foundations for the major study, Evaluation Study 3. There were only a few participants in the questionnaire survey, one expert evaluator and four learners.

Pertinent problems and needs reported by evaluators, were:

- Adjustment to the privileges settings for use of the blog feature;
- Customisation of the glossary options;
- Improvement to the look and feel of *m-LR*$_2$. Specific changes were suggested to font styles, size and colour;
- Restructuring of the quiz to exclude open-ended items.

Furthermore, some evaluators struggled with the username and password requirements. This was adjusted for *m-LR*$_3$ by simplifying the login procedure. Certain evaluators experienced navigation difficulties when using their mobile phones. The suggestion was made that it might be easier to navigate *m-LR* using a Samsung Galaxy 10.1 Tablet. However the research strategy was not adjusted to incorporate this idea. The other refinements were duly implemented, culminating in *m-LR*$_3$.

Evaluation Study 3: This was one of two major evaluation studies. It led from *m-LR*$_3$ to *m-LR*$_4$. Five expert evaluators participated in the HE and seventeen learners in the questionnaire survey. Feedback from both groups identified required improvements, which were implemented in *m-LR*$_4$:

- Correction of an unsatisfactory Help facility;
- Redesign of the built-in support documentation provided by Moodle;
- Re-arrangement of navigation links to simplify flow;
- Improvement to navigability, adding 'breadcrumbs' for path-finding;
- Streamlined video and slide show content, enabling greater compatibility;
- Assessment of compatibility of online media with a range of device types;
- Problems with buffering addressed by decreasing file size;
- Clarification at the beginning of each lesson of goals and learning outcomes;
- Greater focus on user-centricity by providing course content in PDF format, ensuring offline readability; and
- Direct access from *m-LR* to Facebook and Twitter.

Evaluators suggested that Internet links to cloud technology such as Dropbox, would increase the appeal of *m-LR* and facilitate communication members of SE project groups.

Evaluation Study 4: Evaluation 4 was another major study, using *m-LR*$_4$ as input and aiming for a future version, *m-LR*$_X$. Five expert evaluators participated in the HE and 33 learners (from two different campuses) completed the questionnaire. The following requirements were indicated:

- Increased focus on design and development principles;
- Consideration of the capabilities and specifications of a greater range of mobile devices; and
- Improved ease of use and better user experience.

Evaluation 4 completed the cycles of evaluations and redesigns. The items listed above have not been implemented, nor has the request for a Dropbox, but these constitute the first requirements for a future full-and-final version, *m-LR*$_X$. This 'incomplete' series is in line with the findings of [2], where a meta-analysis of 47 DBR studies revealed only one completed series with a final version of the designed artifact. Although all four versions of *m-LR* are fully operational, none can be considered an ultimate artifact.

6.4 Digital profile studies

The two digital profile studies investigated what mobile technologies the learners used, as well how, where and when they used them. The findings provided insight into the context and complexity of the problem, as well as the naturalistic milieu of this research. Although the results did not influence redesign, they strengthened knowledge of the learners' personal contexts and contributed to understanding of the left tower and upper environmental conditions of Figure 2 for this study. A brief summary follows:

Digital Profile Study 1 associated with Evaluation Study 2: This entailed a survey questionnaire among 36 learners from the two campuses. Their digital profile data was collected prior to the selection of participants for Evaluation Study 1 [14]. Feedback indicated differing modes of transport and the usage of diverse brands and models of mobile phone. *Facebook* was a popular digital communication mechanism and could provide a collaboration platform for group work. Very few participants reported prior use of mobile devices for educational purposes. Finally, the profiles revealed a paradox associated with the existence of a digital divide as well as a digital difference.

Digital Profile Study 2 associated with Evaluation Study 4: This study, in which 35 learners from the two campuses completed questionnaires, had a two-fold purpose:

- Collection of quantitative data regarding mobile devices, the brands, usage and location of use; and
- Collection of qualitative data exploring learner attitudes to a mobile technology strategy.

Learners reported the use of mobile phones with diverse capabilities, describing how they used their phones in different locations, carrying out a range of activities other than telecommunications. The wide range of devices suggested that an m-learning environment might have limited success. Some negativity to the technology emerged, indicating that attitudes needed to be cultivated [14].

7. DISCUSSION

The goals of this paper are now revisited in the light of the preceding content.

7.1 Goal 1 – Refection on DSR and DBR

The first goal was to present the principles and approaches of DSR and DBR and consider their similarities and differences. Based on Sections 4 and 5, Table 2 compares their goals, features and processes, demonstrating strong similarities.

Table 2: Summary and comparison of DSR and DBR as research designs [1; 3; 4; 6; 8; 13; 15; 21-23; 29; 34; 36; 37]

	Design-science research (DSR) in IS	**Design-based research (DBR) in educational technology**
Goals and ethos	Design of new man-made artifacts to solve complex problems: constructs, models, methods, instantiations. Problem-solving via invention, evaluation, measurement, and impact studies. Work based on existing design theories. Generic process models and methodologies are proposed. Communication to academics and professionals	*Dual outputs of each study* *Practical outcome*: Implementation of novel educational-technology solutions in complex situations. New products and practices in real-world settings. *Theoretical/scientific outcome*: Development/extension of models and contextual design theories/design principles. Design principles shared with practitioners and designers.
	Both are pragmatic, approaching design from a practical perspective. DBR does so as a primary consideration. Both contribute to knowledge, but it is not an integral requirement that each DSR study should make a theoretical contribution. Both reflect on the nature and role of theory.	
Distinct features	Rooted in engineering approaches. Problems in ill-defined, complex areas, approached by creativity and teamwork. Solutions appropriate to the environment Use of novel artifacts to change real-world states. 'Satisficing' findings, obtaining satisfactory solutions but sacrificing exhaustive search.	Rigorous and reflective analysis of real problems in education or training. Multi-disciplinary expertise. 'Design experiments' that result in innovative designs and prototypes, as well as theoretical outputs Contextually-sensitive approach.
Processes	'Design' relating to both products and processes. *Products:* complete systems and building blocks, i.e. constructs, models, methods and instantiations. *Processes:* complementary activities of construction-in-context and cyclic evaluation in which criteria and metrics are developed in context.	Convergence of research, design and feedback. Continuous cycles of analysis, design, development, enactment, evaluation and redesign. Pragmatic inquiry, evidence-based claims, validation by use. Interpretive paradigm, qualitative studies and mixed methods.
	NB Both have iterative cycles of design, rigorous evaluation/testing and refinement	
	IS traditionally took positivist stances, but is tending to employ interpretive paradigms as well.	DBR methodologies and frameworks apply interpretive paradigms, qualitative studies and mixed methods research.

Common features

We briefly summarise and consolidate the key features of Table 2 by indicating that design research, whether DSR or DBR, addresses complex real-world problems by supporting the iterative design of innovative solutions to do real work in a context of use.

Contrasts

Design research in e-learning (i.e. DBR) has different methodologies and frameworks from the design research of pure IS (DSR) with its software engineering roots. DBR's foundations are related to pragmatic philosophies and inquiry, stressing practical applications in educational institutions, including schools. DSR, however, highlights the role of formal theoretical frameworks, prescriptive design theories, and methodologies that should impact on uniformity and rigour of the research. IS research is frequently applied in business and government situations.

There are differences in the outputs. DSR defines varying types: constructs, models, methods and instantiations (implementations), some of which are components of others. Theories resulting from DSR should be considered as 'knowledge contributions', not as outputs [13]. However, DBR explicitly promotes dual outcomes as part of the research process. There should be a practical output (an implementation or intervention) that changes real-world practice, and a theoretical outcome, which may be a framework-style conceptual artifact.

7.2 Goal 2 – Reflection on the application of DBR

We investigate the conformance of the development of *m-LR*, to the tenets of DBR. With regard to the factors in Table 1, it is evident from Sections 6.2 and 6.3 and from Figure 4 that *m-LR*'s development process adhered closely to DBR principles.

Real-world complex problem: Dichotomy between student bodies; dependence of some learners on their mobile phones.
Innovation: *m-LR* was an innovative pioneering effort.
Iteration: Four cycles of inter-related design, evaluation, analysis and redesign, enriched by digital profile data.
Context: Participants evaluated *m-LR* in action, using their own devices for learning activities in natural settings.
Systematic approach: Well-structured design and evaluation methodologies; evolutionary step-wise changes to artifact.
Empirical research: Two evaluation methods (HE and end-user surveys); triangulated data. Findings used in refinements and to impact on teaching and learning practices.
Communication and publication: This paper is the second publishing venture on this work. The first was [14].

Textual discussion follows of *m-LR*'s conformance to other DBR features. Regarding the *dual outcomes*, the *practical* real-world product was a set of versions of *m-LR*, operational m-learning environments. The *theoretical* culmination was a custom-built evaluation approach, *MUUX* (to be described in separate work), based on five categories of criteria: interface issues, usability of the web-based environment, educational usability, m-learning factors, and user experience. MUUX was developed in a *pragmatic* way and its criteria did effective work in the evaluation studies. An intriguing aspect was our reflection on whether this iteratively-developed theoretical evaluation framework is a designed and evaluated object in its own right. The literature supports this possibility. Amiel and Reeves [1: p. 35] say of the theoretical outcome, that similar to the practical output '...design principles will undergo a series of testing and refinement cycles'. In DSR literature, the pioneers March and Smith [21] state that the evaluation criteria themselves must be designed.

Problem solutions should be *grounded in existing theory*. The real-world situation was complex and challenging, with little prior theory on designing extensive multi-purpose m-learning environments. Literature sources provided certain principles that were synthesized into guidelines for the initial design and development of *m-LR*. Due to the dynamicity of mobile devices, the domain shifted over the 3-year study, making the situation more complex. However, the evaluation framework was firmly based on existing theories.

Indeed there was *synergy* as design, research, theory and practice all advanced simultaneously.

The study excludes production of the final version, *m-LR*$_X$. This too, is in line with related work described by [2].

8. CONCLUSION

This meta-research study outlined two research paradigms, DSR in IS, and DBR in educational technology, which emanated independently from Herbert Simon's design science. There are close similarities, as Section 7.1 demonstrates, yet there are also distinct differences, for example, stances on the balance between theory and pragmatism.

We introduced a South African m-learning application, which adhered closely to DBR in its development, research and evaluation processes, described in Section 7.2. DBR's iterations provide rigour and flexibility that accommodated the dynamic nature of mobile technology and m-learning contexts and the evolving differences in digital populations.

The findings of this study suggest that DBR is an appropriate research paradigm for designing and evaluating mobile technology artifacts that enhance learning in cases where tertiary learners are, by choice or of necessity, on the move.

A limitation is the duration of design research studies – does DBR take too long in a milieu where agile methodologies emphasize rapid turnarounds? Technological capabilities, trends, attitudes, skills and requirements change rapidly and may require new rounds of research and design after short periods. This would call for researchers with time and energy, as well as technical skills and domain knowledge.

An alternative would be an adaptation of DBR to short cycles or to less cycles. This would suit the requirements of rapidly evolving forms of education, such as m-learning with its dynamic nature. However, rapid collection of diverse data, followed by analysis and interpretation, would create high volumes of work, possibly calling for a team approach. If the research was undertaken for postgraduate studies, a team approach would be inappropriate, unless a roles-within-team approach was implemented in a cohort supervision model.

To conclude, design science research (DSR) is being promoted within SA [27], but DBR is less known. Is it time for a South African from the e-learning or m-learning community to emerge as champion for design-based research?

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