Using design science in educational technology research projects

Susan M Chard
Whitireia Polytechnic, New Zealand
Email: Sue.Chard@whitireia.ac.nz

ABSTRACT

Design science is a research paradigm where the development and evaluation of a technology artefact is a key contribution. Design science is used in many domains and this paper draws on those domains to formulate a generic structure for design science research suitable for educational technology research projects. The paper includes guidelines for writing proposals using the design science research methodology for educational technology research and presents a generic research report structure. The paper presents ethical issues to consider in design science research being conducted in educational settings and contributes guidelines for assessment when the research contribution involves the creation of a technology artefact.

Keywords: Design Science, Educational Technology, IT artefact, Assessment.

INTRODUCTION

Research projects involving the design and development of technology artefacts are common in education. Education research often involves the creation and or trial of information and communications technology tools within the learning environment. Opportunities for the use of an information technology artefact are identified and then a trial ensues to evaluate the use of the artefact in a particular situation. Examples include the use of online systems such as Facebook and Moodle, or the inclusion of laptops and tablets within a classroom situation or the use of a particular software program to support learning mathematics or the use of technology tools to monitor student progress. Often these studies include development of software or selection of hardware.

The motivation for this paper is to address two issues that arise for such projects. The first issue is that these projects encompass both the social sciences and the artificial sciences. Education research frequently focuses on social science projects, where clear guidance on research design is readily available. When a research project involves developing a technology artefact, to address a problem, the research project belongs in the realm of artificial science. Research design guidance is less readily available in artificial sciences, particularly for information technology research projects. The second issue is that research projects creating artefacts such as software must be designed, reported, and assessed as research projects. These projects must be clearly distinguishable from industry-based software, system or application development projects as typically performed in the Information Technology industry.

The overall issue that this paper addresses is: how education research involving the creation of an artefact, such as a software application, as a key contribution be rigorously designed, reported, and evaluated? This paper demonstrates how the design science research paradigm provides a solution to this issue. The paper proposes a generic structure based on design science research, for technology artefact focused education research projects. Design science research is proposed as a suitable paradigm because it is commonly used in domains such as information and communications technology, information systems and engineering.

The use of design science research in information systems and information and communications technology research underpins this proposal that design science research is a useful methodology to consider in education research. This paper draws on design science research literature from the domain of information and communications technology and information systems to propose guidelines suitable for education design science research project proposals and reports. Ethical concerns for such projects are described.

Research in the sciences of the artificial

Research can be characterized as research in natural sciences, social sciences or sciences of the artificial. Natural science studies measurable criteria in the physical world with a view to describing, understanding and predicting the natural world . Well established research methodologies in natural science are often referred to as the scientific method which is a group of techniques to investigate phenomena based on empirical and measurable evidence (Newton, Bernoulli, MacLaurin, & Euler, (1999) [1687, 1713, 1726]). These techniques include observation and experimentation with many methods to ensure repeatability and quality assurance included in the processes. Social science focusses on the study of human society and social relationships (Dictionaries). Social science includes the majority of education research which often emphasizes quantitative and qualitative approaches, which may be combined into mixed methods research. This field is based on the foundations for different types of empirical research including scientific and positivist, naturalistic and interpretive, mixed methods (Cohen, Manion, & Morrison, 2013). Both natural and social sciences explore phenomena that occur in the natural world, to develop descriptions, understandings and develop predictive theory.

The field of design science research is concerned with the creation of the artificial. It focuses on the creation of new artefacts to address issues and develop new opportunities and understandings "challenge what is, incite what could be, and help imagine a world that is not yet" (Fine, 1994, p. 30). It involves its own particular facets of the philosophy of science. These facets involve the purposeful creation of artefacts and the introduction of these artefacts into natural settings. Because these artefacts are both artificial and embody adaptive intent, the study of these artefacts is philosophically different from natural science and social science. Design science research appears to be more of a research paradigm than a research methodology (Iivari, 2014). Design science research ranges across many academic disciplines such as architecture, engineering and information systems. It is a methodology utilized for research in many domains. It is acknowledged as a methodology which focuses on the "pragmatic creation and investigation of the artificial based on theory" (Chard & Strode, 2014) . A research methodology in the information systems discipline in which new knowledge is produced by the construction and evaluation of artefacts, broadly defined as software, composite systems of software, users and use processes, and information and communications technology related organisational methodologies and interventions. Key features distinguishing Design Science Research include the ability to explore new areas, utilizing constructivist rather than statistical methods, and the ability to build as well as test theory (Vaishnavi & Kuechler, 2015).

Distinguishing between design research approaches

Applied research in education has aimed to improve educational practice. Cronbach and Suppes (1969) called this applied research decision-oriented research. With the introduction of the learning sciences in the 1990s, research oriented toward the creation and improvement of designs for educational practice gathered strength (Bereiter & Scardamalia, 2015). There are now a number of different research approaches, commonly used in education research, which use the term design. These include Design Based Research, Design Experiments, and Design Research. These are separate methods and although related are not Design Science Research.

Design Based Research, aims to solve existing real world problems experienced by practitioners by analysing the situations, designing and implementing interventions, then evaluating the outcomes to extend theories (DBR_Collective, 2003). Design based research involves introducing innovations into real world situations rather than constrained laboratory contexts and examining the impact of those designs on the learning process. Designed interventions may include instructional methods,

software or materials. The research findings are then iteratively cycled back into the next iteration of the research to produce new design innovations in order to build evidence of the particular theories being researched. The aim is to use the research to positively impact practice and the diffusion of the innovation (Kelly, Lesh, & Baek, 2014). The Design Based Research Collective, posits that design-based research will assist educators to narrow the chasm between research and practice. Part of the challenge is that research that is detached from practice "may not account for the influence of contexts, the emergent and complex nature of outcomes, and the incompleteness of knowledge about which factors are relevant for prediction" (DBR_Collective, 2003). While there is an ongoing debate about what constitutes design-based research (Van den Akker, Gravemeijer, McKenney, & Nieveen, 2006), the definition of design-based research proposed by Wang and Hannafin (2005) captures its critical characteristics as

"*a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories*" (Wang & Hannafin, 2005, p. 6).

Joseph (2004) has listed three important characteristics of design-based research. First, design-based research creates opportunities for focusing on key questions, as in the case where a pilot study identifies a need for more intensive theorizing. Secondly, design-based research supports design progress with both formal research backing and rapid prototyping for example solving certain problems without attempting to understand them deeply. Thirdly, in design-based research, emergent theory shapes research methods as well as design. The conjoined goals of developing effective designs and contributing to basic understandings create, through their interactions, a powerful engine for driving innovative work in education (Joseph, 2004). Design-based research is characterised as a unique enterprise by a commitment to understanding learning and instructional practice in authentic contexts and improving a program through iterative experimentation. Most design based researchers study learning in rich contexts that can account for all the "messiness" that traditional laboratory studies seek to eliminate. As such, design based research is a useful framework for educators studying learning in existing classrooms and who have the ability to tweak or improve these environments toward building a better theory of learning or instruction (Barab & Squire, 2004).

Design experiments, involve the design of an experiment with a control and a test group. Design experiments are pragmatic as well as theoretical. Design experiments are used to study both the design of learning and the resulting environment of learning. This emphasis on function in a real world context applies for all design experiments even though they may be conducted in a diverse range of settings that vary in both type and scope (Cobb, Confrey, Lehrer, & Schauble, 2003).

Design research, is the systematic process of designing, developing and evaluating educational interventions, - such as programs, teaching-learning strategies and materials, products and systems, as solutions to practitioner problems. It also aims at advancing knowledge about the characteristics of these interventions and the processes to design and develop them. It is perceived as an approach suitable to address complex problems in educational practice for which no clear guidelines for solutions are available. (Van den Akker et al., 2006)

Design science research is proposed as a method suitable for research involving creation of an artefact as a major output. Design science research is used in many disciplines including Engineering, Health Sciences, Computer Science, Management Sciences and Information systems. It involves theory based design, creation of artefacts, positioning of these in a natural setting with evaluation of the artefact based on theory. Although the various disciplines have somewhat differing perspectives on design science research they demonstrate a common theme that focuses on the practical creation of the artificial based on theory. This involves identifying problems and designing solutions following theory based design practices, the creation of an artefact, and the positioning of the artefact in a natural setting for evaluation.

Information systems and computer science each have their own interpretation of design science research. In information systems , design science research is common in European and Scandinavian countries and is the leading research paradigm in German speaking countries (Winter, 2008). Information systems design science literature commonly refers to Simon's seminal "Sciences of the Artificial" (Hevner, March, Park, & Ram, 2004; March & Smith, 1995; Simon, 1981). Hevner and Chattergee (2010) describe how design science research addresses wicked problems, and the relevancy gap between academic research and practitioner problems in information systems. Baskerville(Baskerville, 2008)) suggests design science research is a useful tool for information systems professionals seeking important design innovations. He encourages information systems academics to employ design science in their research, and teach design science research to graduate and undergraduate students to improve their capabilities. Further research focuses on the place of theory in design science research (Gregor & Jones, 2007). Several information systems authors identify the need to differentiate professional systems design from design science research. Hevner and Chatterjee (2010) propose that this difference is in the nature of the problems and their solutions, while others highlight the role of theory and evaluation. There is agreement however, on the need to add to knowledge and that the knowledge should inform best practice.

In computer science, (Holz et al., 2006) list 54 research methods including design science. Research methods used in computer science include theoretical and experimental computer science, and modelling, although a large proportion of the computer science literature does not specify or define a formal research method. In this domain, examples of design science research are primarily found in artificial intelligence and human computer interaction research (Preston & Mehandjiev, 2004; Reinecke & Bernstein, 2013).

Design science research among software engineering researchers generally seeks better methods to develop and evaluate software. Software engineering is motivated by practical problems and attempt to solve these problems by creating and evaluating new techniques and procedures, or by developing analytical models (Shaw, 2003). Recent literature proposes using design science research in software engineering to promote collaboration between researchers and industry. Examples of collaboration successfully applying design science in software engineering are given by (Rodríguez, Kuvaja, & Oivo, 2014). In this instance, the design science is described as a constructive research paradigm for developing innovative artefacts while creating new knowledge through the rigorous design and evaluation of the artefact.

Design science is also proposed in other domains that inform information technology research. Engineering design science was proposed by Hubka in 1976, cited by (Eder, 2012) who proposed that its primary purpose is to clarify design processes and their underlying theories through the investigation of the product. This form of design research is conducted with scientific tools and described in formal and general terms. In management research, project management research, and medical research design science is used to develop knowledge for the design and realisation of artefacts (Murad, Schooley, Horan, & Abed, 2014; Van Aken & Romme, 2012).

In summary, there is general agreement across many disciplines that design science research, focuses on the pragmatic creation and investigation of the artificial based on theory. This involves identifying and designing solutions to problems through theory based design, and the creation and positioning an artefact in a natural setting. In addition, design science research addresses design tasks faced by practitioners to develop understandings of what works and why it works, providing a useful tool for collaboration between multidisciplinary researchers, industry and academia.

Design science research in education technology research projects
Education research projects involving the design and creation of technology artefacts and or the trial of information and Communications technology tools within the learning to evaluate the use of the artefact/tool in a particular situation are particularly suited to the use of the design science research methods. These research projects create artefacts such as software, and must be designed, evaluated, and reported as research projects. These projects must be clearly distinguishable from industry based

software selection, systems and application development projects as are typically performed in the Information Technology industry. Design science research is proposed as a suitable paradigm to provide a solution to this issue.

The following three tables present guidelines for the evaluation of research proposals, structure of reports and a summary of ethical considerations derived from the literature on design science research discussed above. Table 1 outlines a generic process to evaluate a research proposal for, technology artefact focused, education research projects to ensure they will be rigorously designed, reported, and evaluated based on design science research methods. This has been adapted from work in information systems design science research (Chard & Strode, 2014; Hevner et al., 2004; March & Smith, 1995; Meyers & Venable, 2014).

Table 1. Guidelines to ensure a sound basis for design science research projects

Guideline	Question /Test
Design as an artefact	What type of artefact(s) will be created?
Problem relevance	To whom and why is the artefact relevant?
Design evaluation	What are the evaluation methods to determine utility, quality, and efficacy of the design artefact?
Research contributions	What are the clear and verifiable research contributions?
Research rigor	Does the research rely on the application of rigorous methods in both the construction and evaluation of the design artefact?
Design as a search process	How is the artefact defined to be good, useful, or valuable? When does the iterative research process end?
Communication of research	How will the research be presented to the audience for whom it is intended?
Ethical considerations	What ethical implications does this research have for current stakeholders and future users of the artefact

Table 2. Research report structure for design science research projects

Chapter	Contents
Introduction	Problem definition/significance/motivation, introduction to key concepts, research questions, goals of the artefact developed, overview of methods, theoretical and practical significance, structure of remainder of the report.
Related literature	Prior work that is relevant to the study, including existing knowledge and theories relating to the class of problems to be addressed, research studies, and findings and reports from practice.
Method	The specific design science research approach that was employed with reference to existing authorities. A description of the process of creating the artefact. Description of the evaluation strategy, including evaluation criteria.
Artefact description	A concise and complete description of the artefact. This description must be at an appropriate level of abstraction so it is clear how the artefact contributes to the knowledge base.
Evaluation and discussion	Evidence that the artefact is useful. The results of the evaluation must demonstrate its worth with evidence addressing the pre-specified evaluation criteria. Interpretation of the results: what the results mean and how they relate back to the objectives stated in the Introduction section and the knowledge and theories discussed in the Literature review sections.
Conclusion	Restate what was done. Restate the important findings and contributions of the research, and why they are important.

Table 3. Ethical Principles for Design Science Research Projects

Area	Principle
Public interest	Explicitly identify stakeholders, affected by the artefact. Critically evaluate benefits and harm the artefact might cause, particularly to the learners.
Informed consent	Obtain consent from all people involved in the research.
Privacy	Protect the privacy of those involved in the research project and also those who will use the artefact in the future.
Honesty and accuracy	Do not plagiarize ideas and acknowledge inspiration from all sources. Report research findings honestly.
Property	Agree on ownership of IP, ownership of information, and rights to publish the research at the beginning of the project.
Quality of the artefact	Identify risk, and evaluate and test the artifact appropriately to ensure safety in use.

Table 2 proposes a report structure for a design science research report. This structure is based on a publication schema for design science research journal articles, published in an editorial to guide researchers submitting design science articles (Gregor & Hevner, 2013). It has been adapted based on recommendations and feedback from other authors (Chard & Lloyd, 2014; Chard & Strode, 2014; Pries-Heje, Baskerville, & Venable, 2008). This structure encompasses the major sections usually found in social science and natural science research reports, while also including sections for a comprehensive description of the artefact created and its evaluation. The description of the artefact needs to be sound and comprehensive so that future researchers and practitioners can build on the research. Lastly the structure ensures that the contributions to praxis and knowledge are conveyed.

Table 3 highlights the ethical implications involved in design science research. These exist even when no research participants are directly involved. Ethical implications arise because information technology artefacts have the potential to contribute both positively and negatively to human society. The researcher should be aware of these issues and address them appropriately. Researchers in information systems research provide extensive discussion of ethical issues in design science research. The ethical principles presented in Table 3 are based on those identified for design science research by Meyers and Venable (2014).

CONCLUSION

This paper proposes that the design science research paradigm is a suitable method to for education research where an information and communications technology artefact is designed and created as a central part of the research process. A similar in structure to that used in the Information and Communications Technology domain has been proposed. This paper has presented general guidelines for research proposals and a generic research report structure suitable for such projects. Ethical principles have been presented as technology artefacts have considerations for design science research projects are embedded within the proposal guidelines and report structure.

REFERENCES

Barab, S. A., & Squire, K. D. (2004). Design-Based Research: Putting a Stake in the Ground. *Journal of Learning Sciences, 13*(1), 1-14.

Baskerville, R. (2008). What design science is not. *European Journal of Information Systems, 17*, 441-443.

Bereiter, C., & Scardamalia, M. (2015). Qwerty and the International Knowledge Building Design Community. *Qwerty-Open and Interdisciplinary Journal of Technology, Culture and Education, 10*(1), 29-36.

Chard, S. M., & Lloyd, B. (2014). *The evolution of information technology Capstone projects into research projects.* Paper presented at the Proceedings of the 15th Annual Conference on Information technology education.

Chard, S. M., & Strode, D. E. (2014). *A proposal for using design science in small-scale postgraduate research projects in information technology.* Paper presented at the Teaching, Assessment and Learning (TALE), 2014 International Conference on.

Cobb, P., Confrey, J., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational Researcher, 32*(1), 9-13.

Cohen, L., Manion, L., & Morrison, K. (2013). *Research methods in education*: Routledge.

Cronbach, L. J., & Suppes, P. (1969). Research for tomorrow's schools: Disciplined inquiry for education.

DBR_Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher, 32*(1), 5-5.

Dictionaries, O. *"natural science". Oxford Dictionaries*: Oxford University Press.

Eder, W. E. (2012). Comparison of several design theories and methods with the legacy of Vladimir Hubka. *Private publication (74 pages) available from eder_e@ kos. net, submitted for web-site of The Design Society, www. designsociety. org*.

Fine, M. (1994). Dis-stance and other stances: Negotiations of power inside feminist research. *Power and method: Political activism and educational research*, 13-35.

Gregor, S., & Hevner, A. R. (2013). Positioning and presenting design science research for maximum impact. *MIS Quarterly, 37*(2), 337-355.

Gregor, S., & Jones, D. (2007). The anatomy of a design theory. *Journal of the Association for Information Systems, 8*(5), 312-335.

Hevner, A. R., & Chatterjee, S. (2010). Design research in information systems *Integrated series in information systems 22*: Springer Science+Business Media, LLC.

Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design science in information systems research. *MIS Quarterly, 28*(1), 75-105.

Holz, H. J., Applin, A., Haberman, B., Joyce, D., Purchase, H., & Reed, C. (2006). *Research Methods in Computing: What are they, and how should we teach them?* Paper presented at the ACM SIGCSE Bulletin.

Iivari, J. (2014). Distinguishing and contrasting two strategies for design science. *European Journal of Information Systems*, 1-9. doi:http://dx.doi.org/10.1057/ejis.2013.35

Joseph, D. (2004). The practice of design-based research: Uncovering the interplay between design, research, and the real-world context. *Educational Psychologist, 39*(4), 235-242.

Kelly, A. E., Lesh, R. A., & Baek, J. Y. (2014). *Handbook of design research methods in education: Innovations in science, technology, engineering, and mathematics learning and teaching*: Routledge.

March, S. T., & Smith, G. F. (1995). Design and natural science research on information technology. *Decision support systems, 15*, 251-266.

Meyers, M. D., & Venable, J. R. (2014). A set of ethical principles for design science research in information systems. *Information and Management, 51*, 801-809.

Murad, A., Schooley, B., Horan, T., & Abed, Y. (2014). Enabling patient Information Handoff from Pre-hospital Transport Providers to Hospital Emergency Departments: Design-Science Approach to Field Testing *Proceedings of the 47th Hawaii International Conference on System Sciences (HICSS)* (pp. 2665-2674): IEEE.

Newton, I., Bernoulli, D., MacLaurin, C., & Euler, L. ((1999) [1687, 1713, 1726]). *Philosophiae naturalis principia mathematica* (I. B. Cohen & A. Whitman, Trans. Third edition ed. Vol. 1). From , 974 pages: University of California Press.

Preston, M., & Mehandjiev, N. (2004). *A framework for classifying intelligent design theories.* Paper presented at the Proceedings of the 2004 ACM workshop on Interdisciplinary software engineering research.

Pries-Heje, J., Baskerville, R., & Venable, J. R. (2008). Strategies for design science research evaluation *Proceedings of the European Conference on Information Systems, ECIS 2008. Paper 87*.

Reinecke, K., & Bernstein, A. (2013). Knowing What a User Likes: A Design Science Ap-proach to Interfaces that Automatically Adapt to Culture. *MIS Quarterly, 37*(2), 427-453.

Rodríguez, P., Kuvaja, P., & Oivo, M. (2014). Lessons learned on applying design science for bridging the collaboration gap between industry and academia in empirical software engineering *Proceedings of the 2nd International Workshop on Conducting Empirical Studies in Industry* (pp. 9-14): ACM.

Shaw, M. (2003). Writing good software engineering research papers: Minitutorial *Proceedings of the 25th International Conference on Software Engineering* (pp. 726-736): IEEE Computer Society.

Simon, H. A. (1981). *The sciences of the artificial*. Cambridge, MA: MIT Press.

Vaishnavi, V. K., & Kuechler, W. (2015). *Design science research methods and patterns: innovating information and communication technology*: Crc Press.

Van Aken, J. E., & Romme, A. G. L. (2012). A design science approach to evidence-based management *The Oxford Handbook of Evidence-Based Management* (pp. 43-61).

Van den Akker, J., Gravemeijer, K., McKenney, S., & Nieveen, N. (2006). Introducing educational design research. *Educational design research, 1*, 3-7.

Wang, F., & Hannafin, M. J. (2005). Design-based research and technology-enhanced learning environments. *Educational technology research and development, 53*(4), 5-23.

Winter, R. (2008). Design science research in Europe. *European Journal of Information Systems*, 470-475.