Framing IT Capstone Development Projects with Design Science Research principles

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ABSTRACT

Focussing on the design, implementation and evaluation of some form of constructed artefact, Design Science Research (DSR) has been gaining ground as a research framework highly suited to the disciplines of Computer Science and Information Technology. This paper describes a simplified version of the framework which is taught to final year undergraduates studying for a Bachelor of Information Technology qualification. The paper considers the value of encouraging these students to use the methodology to frame their final year capstone development projects and describes the results that have been achieved. It concludes by summarising the benefits for both those students who choose to continue into postgraduate study and those who move directly into the IT industry.

Keywords: capstone projects, development projects, design science research

1. INTRODUCTION

Preparing students for life after graduation, whether in industry or further study, is a primary concern of IT educators. The range of required professional skills continues to increase for 'work-ready' graduates while those students intending to further their study are expected to have at least an introductory background to various academic activities. The need to provide students with the opportunity to follow either the academic or the professional path requires a careful balancing act if the limits of a busy curriculum are not to be breached. Fortunately a number of the skills are essential to both pathways; critical thinking, problem-solving, technical knowledge and appropriate communication being the most obvious. However, an understanding of the academic research process is one area that may be sacrificed, in the (mistaken) belief that is not of value to those students on the industry pathway who are generally in the majority within any cohort.

It is common practice within IT education to require students to complete a capstone project which is intended to be the culmination of their studies throughout the degree. It is also common for these projects to be completed by a team of students working closely with an industry partner or client (e.g. Mann and Smith, 2004, Skelton and McLay, 2007). In these situations, considerable experiential learning occurs as students interact with the demands of an authentic project. However, for a variety of reasons, some institutions have different requirements and capstone projects may include academic research work, an individual development project or workplace internship. Whatever form the capstone project may take, it is very clearly a major stepping stone on the student's career pathway.

Over the last ten years or so, Design Science Research has gradually emerged as an accepted and useful approach for guiding research in the applied computing fields. Initially developed as an approach in other applied disciplines such as architecture, engineering and education, DSR is primarily focused on the rigorous design, development and evaluation of an 'artefact' . As Hevner et al (2004) say "[I]n the design-science paradigm, knowledge and understanding of a problem domain and its solution are achieved in the building and application of the designed artefact." It has emerged to answer the challenge issued by March and Smith (1995) that "[R]esearch in IT must address the design tasks faced by practitioners. Real problems must be properly conceptualized and represented, appropriate techniques for their solution must be constructed, and solutions must be implemented and evaluated using appropriate criteria."

While acknowledging that it may not always be appropriate, this paper argues that bringing the discipline of the DSR approach to the development of an IT solution within a capstone project provides final year students with a means of understanding not just the needs and requirements of industry but also the wider skills of understanding and applying a research, evidence-based approach to their work. By this means, students are exposed not only to the reality of reflective industrial practice but also to the academic practice of applying and using a research approach.

2. BACKGROUND

2.1 Capstone Projects

Capstone projects have become accepted as an effective means of both synthesising a large body of knowledge and requiring its application to a specific and well-identified domain. To encourage and practice necessary teamwork skills and to engage students with the demands of the IT industry, projects which are completed in teams within an industry context have much to commend them. However, this is not always possible for a variety of reasons. Students may be studying at a distance from each other or expecting to work as a sole contractor; the location of study may not provide sufficient or appropriate industry partners or the students themselves may be moving into postgraduate study. In such situations, team based industry projects may be neither possible nor desirable.

Small regional institutions are ones where such circumstances are likely to exist. At Nelson Marlborough Institute of Technology, for example, both the size of the student cohort and their access to suitably-sized IT workplaces are limited. The primary learning outcome of the project course is that students will work independently and apply analytical and critical decision making in the planning, organisation and implementation of a project within a specialist field. Students are free to choose between a work placement, if one can be arranged, an academic research project or a development project. The requirements of the various majors also require

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that whichever type of project is undertaken it must have relevance to the specific major that the student wishes to complete. For all projects, apart from work placements, each student is allocated a staff supervisor who will guide, advise and mentor them throughout the semester.

Each year a small number of students will arrange work placements or undertake research and providing a framework to guide and manage such student work is generally straightforward. However, the more common scenario is that a student will identify a development idea that they wish to pursue. This may entail working with a 'real' client but also allows students to develop an entrepreneurial idea to a proof of concept stage or to explore and experiment with a using a new technology or creating a new application of their own. While working as a team is not excluded, the expectation is that such projects will be undertaken individually. Providing a guiding framework for these kinds of projects is more problematic. All students will have a basic understanding of the systems development process, although some may not have applied it independently before, and while it is obviously appropriate for many of these projects it does not necessarily provide a straightforward framework for critical analysis or personal reflection on the work that has been done. It is here that framing such projects as Design Science research can help with formalising aspects of the project work that are not adequately covered by a systems methodological approach.

2.2 Design Science

As a research framework Design Science for Information Sciences has its roots in other applied disciplines such as Architecture, Engineering and Education. Much applied research is concerned with the design, creation and evaluation of a product, in DSR known as an 'artefact', constructed in response to a specific human need. This 'need' may also incorporate the aesthetics of the artefact as well as its functionality. However, DSR also recognises that design is a process as well as an artefact (Hevner et al 2004). Consequently it considers both, and as Hevner et al (2004) comment "evaluation of the artefact then provides feedback information and a better understanding of the problem in order to improve both the quality of the product and the design process...During this creative process, the design-science researcher must be cognizant of evolving both the design process and the design artefact as part of the research" (p.78). Hevner et al (2004) also provide a set of guidelines for DSR which attempts to reconcile the important rigour vs relevance debate. The seven guidelines (adapted from Hevner et al, 2004) are:

- 1. DSR must produce a viable artefact in the form of a construct, a model, a method, or an instantiation.
- 2. The objective of DSR is to develop technology-based solutions to important and relevant problems.
- 3. The utility, quality, and efficacy of a design artefact must be rigorously demonstrated via well-executed evaluation methods.
- 4. Effective DSR must provide clear and verifiable contributions in the areas of the design artefact, design foundations, and/or design methodologies.
- 5. DSR relies upon the application of rigorous methods in both the construction and evaluation of the design artefact.
- 6. The search for an effective artefact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.
- 7. DSR must be presented effectively both to technology-oriented as well as management-oriented audiences.

Based on these seven principles and guided by reported experience from other disciplines Peffers et al (2007) developed a Design Science Research Methodology (DSRM) for Information Systems which categorised required activity into the following six steps (Table 1).

Table 1: Six design science activities, adapted from Peffers et al. (2007.)

Activity 1	**Problem identification and motivation** Define the specific research problem and justify the value of a solution... Resources required for this activity include knowledge of the state of the problem and the importance of its solution.
Activity 2	**Define the objectives for a solution** Infer the objectives of a solution from the problem definition and knowledge of what is possible and feasible...Resources required for this include knowledge of the state of problems and current solutions, if any, and their efficacy.
Activity 3	**Design and development** Create the artefact. This activity includes determining the artefact's desired functionality and its architecture and then creating the actual artefact. Resources required moving from objectives to design and development include knowledge of theory that can be brought to bear in a solution.
Activity 4.	**Demonstration** Demonstrate the use of the artefact to solve one or more instances of the problem. This could involve its use in experimentation, simulation, case study, proof, or other appropriate activity. Resources required for the demonstration include effective knowledge of how to use the artefact to solve the problem.
Activity 5	**Evaluation** Observe and measure how well the artefact supports a solution to the problem. This activity involves comparing the objectives of a solution to actual observed results from use of the artefact in the demonstration. Conceptually, such evaluation could include any appropriate empirical evidence or logical proof.
Activity 6	**Communication** Communicate the problem and its importance, the artefact, its utility and novelty, the rigor of its design, and its effectiveness to researchers and other relevant audiences, such as practicing professionals, when appropriate.

Inherent in the DSRM is the understanding that while the process appears sequential it can be started or completed at any useful point and that iteration, as a result of knowledge gained through the various activities, is to be expected. The similarity of this methodology to other system development methodologies used by IT practitioners is perhaps unsurprising but it adds significant value by requiring (or at least encouraging) a more rigorous evidence based approach to the normal activities of professional practice.

While there are many flavours of Design Research, and still considerable debate within the IT research community as to how it is best defined and utilised, a simplified but still rigorous version, true to the seven principles listed above and suitable for use with undergraduate students, can be derived.

2.3 In the classroom

In 2010, design science research was introduced into a final year undergraduate research methods course as one of various appropriate approaches to IT research. For students who were primarily concerned with development activities in other areas of their degree, the concepts within DSR appeared to resonate and what began as a basic introduction to the approach has gradually become a more fundamental part of the course. Almost all students take this course in preparation for their final capstone project (Project Management is the alternative course open to them) even if further research is not part of their future plans. In order to make the approach more accessible to undergraduate students, a simplified version was taught. This sought to remain true to the spirit of Pfeffer's framework (2007) but which which mapped to a model familiar to Information Technology students. The following five primary steps were identified:

1. Identify the problem - figure out what you are trying to do and why you are doing it, who are you doing it for and whether it is worth doing and what you intend to achieve.

2. Design the solution - use all of the above to identify any other solutions, or closely related solutions that exist; figure out what combination of technology or technological approaches will bring the most value to your solution; bring all the knowledge you have gained into designing your new solution.

3. Implement the solution - create the new solution to a stage where it can be demonstrated to either the target audience or a proxy.

4. Evaluate the solution - identify effective ways of evaluating the solution; undertake and formally record the evaluation; identify the impact of the evaluation on the problem, the design and the implemented solution.

5. Communicate the work – record all important activities from the previous steps, including previous work, new thinking, decisions made, mistakes made and problems solved. Make this record accessible in various forms as appropriate (e.g. written report, poster presentation, website or blog.)

Broken down into these stages and steps, the match between systems development and the principles of DSR is obvious. The approach provides for a measure of academic rigour and formality around standard professional practice and students have little difficulty in seeing both the connection and the value of this. This has had two immediate benefits. Firstly, it has provided a mental model of a research framework that IT students can easily identify with. Secondly, it allows for the discussion of research activities such as literature reviewing, experimenting and evaluating to take place not in some abstract realm of academic practice but in an immediately relevant context.

3. DSR IN ACTION

As a result of the increased focus on DSR in the course, several students have chosen to use it to assist in the framing and management of their final capstone projects. One clear advantage in taking this approach has come from the ability of the student to focus on the specific parts of the process most relevant to their project work. Guided by Peffers et al (2007) which suggests various entry points (and by implication exit points) into the process, students could identify which entry and exit points were most suitable for their topic area and most likely to be attainable within the fairly limited time-frame of their project work. Two examples are considered here in more detail.

3.1 Example 1

Student A was interested in understanding the difficulties faced by new learners of database theory and exploring the possibility of constructing some form of virtual environment learning experience which could aid their understanding. The project contained a significant element of classic research in terms of identifying learner difficulties and previously constructed solutions and a significant element of experimental development in creating an immersive artefact in a virtual world as a means of constructing a new solution. Given his lack of 3D building expertise, he was more interested in identifying the problem in depth and implementing a 'proof of concept' solution rather than attempting to build a fully functional solution. He identified that Step 1 would be his entry point and that steps 1 and 2 would require the bulk of the time that he had for the project. There would be little time to develop the solution and a small proof of concept implementation would be all that could be considered. In recognition of this, he adapted the framework by using a three stage approach, "A modified version of the design research methodology was used. Instead of 4 different stages, 3 were designed. Stage 1 is to identify and analyse the problem, as well as to define the objective. Stage 2 is to design and develop the artefact. Stage 3 is to demonstrate and evaluate what was done in the previous stages. Only the first 2 stages were used in this project." (Green 2013 p.27).

3.2 Example 2

Student B wished to create a Second Life space usable by an existing community and decided to utilise the Design Science Framework to assist in identifying the various aspects of her project. While ideally, she would have preferred to have given equal weight to all aspects, time constraints required her to prioritise and she felt that DSR would enable her to focus more efficiently on those areas which she wished to emphasize. She also used the 4 stages of the simplified framework described above and decided to use Step 1 as her entry point. However, she felt it likely that Steps 1 and 2 would require less of her time and that her focus would be on the third step which involved the creation of a community space within in a virtual world. This decision allowed her to spend some time in exploring the characteristics of a successful online community (step 1) and designing a space to encourage those characteristics (step 2) but kept the creation and evaluation of her artefact as the central focus of her project.

4. VALUE AND BENEFITS

The benefits to the students of taking this approach were considerable. In example 1 the initially perceived need to build a complete and fully functional artefact that could be properly evaluated was recognised as unrealistic given the time-frame and unnecessary given that a proof of concept was in itself a substantial outcome of the research. This allowed the student to focus on the definition of the problem, what aspects of database theory do new learners find most problematic, to evaluate solutions that others had suggested and found wanting, to suggest a new solution and to prove that it was possible to create the solution. The question of whether the new solution was effective or how it could be improved then sat beyond the scope of the project.

In example 2, while it was necessary to be familiar with the literature on successful online communities, the requirements for the creation of the virtual space were reasonably well known and able to be captured reasonably easy. The challenge in this project was the actual creation of the space and then the evaluation of it as a successful environment for various outreach activities. The student was thus able to ground their development work in relevant research without losing the focus on the skills required for the artefact construction.

4.1 Student assessment of value

Both students commented within their respective project reports of the value of the approach. Student A commented:

> The design research methodology has proven to work well for this project. Due to its iterative nature it was possible to take a step back and look at the previous stage again. This was done many times throughout the project. Sometimes it was best to go back and look at the metaphor, think about how it should be constructed, then go back to building it. (Green, 2013. p.23)

Student B agreed and remarked:

> Applying the framework provided the project with a direction and outlined its purpose, by identifying the problem and seeking the questions to the problem and researching the answers. Moving through the stages gave clear guidelines to expected outcomes of what was to be achieved throughout each stage, allowing room to move back and re-evaluate decisions made at early stages that were not working and make appropriate amendments. It defined the artefact's scope, making it easier to define milestones and make decisions. (Taylor, 2013. p.23)

4.2 Response of Examiners

Both students scored highly in the assessment of their final project reports with A or A+ from both the technical and report writing examiners. Part of their success was clearly down to the logical and structured way they were able to show how their development work was grounded in research literature. This enabled them to demonstrate not only that they had technical competence in various areas but also that they could apply those skills in a controlled and disciplined manner. They both avoided the common trap of development capstone projects of not paying attention to the context in which they were working by considering previous relevant work and literature.

5. DISCUSSION

There is clearly an easy match to be made between Information Systems development methods and the design science research framework as both are concerned with the production of a 'fit for purpose' artefact grounded in best professional practice. The framing of a development project as design science research within an academic environment ensures that the important context of previous work and literature is not overlooked. In addition, the student is able to demonstrate an understanding of research methods and their application to a practical activity as well as their ability to complete a technical piece of work. It also provides a clear pathway through a complex activity and allows for controlled iteration and scoping when needed.

For the students, a simplified version of Design Science Research is an intuitive model to follow for this kind of work and, as in the examples above, allows them to investigate new areas and skills within a safe and reasonably controlled environment. It also allows for the primary focus of a development to be tailored to the needs of the project by giving the student different entry points to the process. For example, it would be straightforward for a student to pick up previous work and focus mainly on the development or evaluation of a design rather than needing to start from a detailed analysis of the original problem. Both of the students discussed above reported verbally that they could not imagine how they would have tackled their project without using DSR and it was interesting how they were able to individually and independently tailor the framework in a way that was most relevant to the work that they were doing.

While the entire framework had been introduced to previous groups of students it had not been adopted by any of them as a method of choice. In retrospect it is likely that the complete framework as set out by Peffers *et al.* (2007) can be somewhat intimidating for beginning researchers, particularly for those who are more interested in IT development rather than research *per se*. The construction of the simplified framework into which the essential elements were distilled was important in making DSR accessible to these students and overcoming the barrier that the term 'research' can create.

6. CONCLUSION

This paper has described the use of a variation of the Design Science Research framework by students completing a capstone project as part of their final year degree studies. Initially taught as a research method in an accompanying Research Methods course, the examples discussed provide evidence of two students choosing to adopt this framework for their development work.

The use of DSR is likely to be particularly useful for independent development projects, where there is no end user/client and where the need has been established by the developer themselves. Partly this is because DSR provides a broader context for the design and construction of an artefact which requires the student to demonstrate an understanding of how their work fits into that larger context.

The adoption of this approach requires students to think of, and ground, their development within a research context rather than treating it as a stand-alone project. This assists the student with the successful completion of their work as well as providing skills that are likely to be valuable in either further study or reflective industry practice.

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