2018

The design and development of E-textbooks to support problem-based learning in secondary school science classrooms

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Chapter Three: Methodology

3.1 Introduction

In this chapter, the Design-based Research (DBR) method is discussed together with the tools used to facilitate data collection and analysis. The chapter considers the design of the problems used in this study and the epistemological approach. The chapter also includes a discussion of the methods for analysing the data, the limitations of the study and its ethical implications.

The purpose of this study was to investigate a set of targeted iterations, at a single secondary school site, which facilitated Problem-based Learning (PBL) in secondary school science classrooms. A key feature of these iterations was that they employed e-textbooks. Thus, the research had two complementary objectives. The first was to examine the extent to which PBL was a useful pedagogical approach in a secondary school science context. This objective necessarily entailed considering whether PBL stimulated a greater breadth and depth of student learning, and also whether any incidental learning (e.g., problem-solving, communication, teamwork skills) occurred. The second objective was to discern the extent to which the e-textbook contributed to the pedagogical approach of PBL and produced incidental learning outcomes (e.g., digital literacy skills). Three research questions were formulated to achieve these objectives:

- What constraints (if any) inhibited the implementation of e-textbook supported PBL intervention?
- What design features of the e-textbook supported PBL intervention most influence student learning?
- What was the overall impact of the e-textbook supported PBL intervention?

Using a DBR method enabled these three research questions to be answered.

3.2 The Underlying Epistemological Approach

Observations and reflection are important attributes for an educational researcher because they allow for the formation of a particular epistemological belief that would guide and inform their practice. The researcher in this study has evolved into a pragmatist. Pragmatism is defined as “action or policy dictated by consideration of the immediate practical consequences rather than by theory or dogma” (Pragmatism, 2012, p. 1559). While acknowledging the value of social constructivism in science education where “meaningful learning occurs when individuals are engaged in social activities such as interaction and collaboration” (Amineh & Asl, 2015, p. 13), real constraints exist in educational institutions. These constraints are owing to factors such as available teaching time and syllabus requirements and they determine that at least initial, basic facts are better taught to students so that they may become more fully involved in later learning experiences using social constructivism when encountering more complex tasks. An example will illustrate this point. While a constructivist approach could be used to help students learn the periodic table, it is more efficient to teach them the structure of the periodic table and then have them use this knowledge as an enabler to engage in learning about chemical formulae and reactions, which are more complex tasks.

The choice of methodology in the current study was not separable from the chosen “theoretical perspective and epistemology” (Case & Light, 2011, p. 188). Mackenzie and Knipe (2006) described four different research paradigms: postpositivist (and positivist), interpretivist/constructivist, transformative and pragmatic. The use of DBR in the current study indicated that a pragmatic paradigm was the best fit for the research undertaken “using data collection and analysis methods…most likely to provide insights into the question with no philosophical loyalty to any alternative paradigm” (Mackenzie & Knipe, 2006, p. 197). Furthermore, with a pragmatic approach “knowledge claims arise out of actions, situations, and consequences rather than antecedent conditions (as in postpositivism). There is also a concern with applications –‘what works’- and solutions to problems” (Creswell, 2003, p. 11). The development of general principles for the use of e-textbooks to support PBL based on the iterative approach of DBR, which was what the current study involved, fits well with this approach.

3.3 Design-based Research

DBR is a relatively recent research method that emerged at the start of the 21st century (Anderson & Shattuck, 2012). Given the large number of methodologies available to researchers (Cohen, Manion, & Morrison, 2011), it is important to explain the use of the DBR method in the current study. DBR, which has also been called design research and development research (Anderson & Shattuck, 2012), has been defined by McKenney and Reeves (2012, p. 7) as “a genre of research in which the iterative development of solutions to practical and complex problems … yield[ing] theoretical understanding that can inform the work of others.” This methodology also uses “the close study of a single learning environment … as it occurs in naturalistic contexts, to develop new theories, artefacts and practices that can be generalised” (Barab, 2006, p. 153). The Design-Based Research Collective (2003) reported that “design-based research methods can compose a coherent methodology that bridges theoretical research and educational practice” (p. 8). Bridging the gap between theory and practice is crucial to the current study, which sought to work within the naturalistic settings of secondary school science classrooms to develop ways of implementing PBL using e-textbooks. A small, but growing, literature base attests to the value of DBR, particularly in considering the use of technology (Barab & Squire, 2004; Herrington & Reeves, 2011; Juuti & Lavonen, 2006; McKenney & Reeves, 2013).

As the study progressed, there was a constant need to reflect on educational practices. The process fitted well with the DBR process, which has a cycle of reviewing the design of a procedure or artefact based on results obtained during the study, with the purpose of improving those procedures or artefacts (Barab & Squire, 2004). This characteristic of DBR allowed the development of solutions "that speak directly to the problems of practice" (The Design-Based Research Collective, 2003, p. 5), which were inherent in the research questions. It also required that the study use design principles that did not just satisfy the exigencies of the immediate environment but also contributed to the broader educational community (Anderson & Shattuck, 2012; Barab & Squire, 2004). Developing design principles served to confirm or refute the utility of the intervention at the local level as well as the wider sphere of science education.

3.3.1 The DBR process

DBR consists of a series of phases (Reeves, 2006) shown in Figure 3.1. This particular model of DBR is implemented in this study. Herrington and Reeves (2011) described the essential requirements of each step:

- The problem is explored intensively … from the perspective of the people who deal with the problem on a day-to-day basis;
- The second phase of educational design-based research focuses on a solution to the problem that can be implemented in the educational setting, such as a classroom or online learning environment;
- The implementation and evaluation cycles of a mature product provide further opportunities to refine design principles;
- Design principles can be ‘captured’ to comprise the sharable, published output from the research to inform future development and implementation decisions. (pp. 297–298)

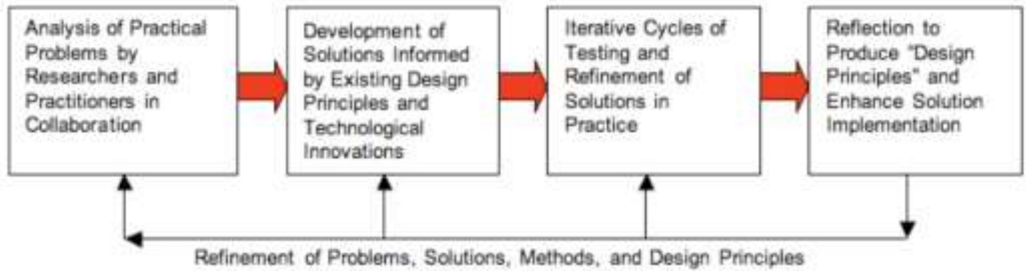

Figure 3.1. The Reeves model of DBR (Herrington & Reeves, 2011, p. 596).

In the current study, all research questions (problems in DBR) needed examination from the viewpoint of the teacher (the researcher in this instance) in the naturalistic setting of the classrooms where the study took place. Doing so allowed possible solutions to the problems to be developed and evaluated. Repetition of the process occurred until a solution was evident that was used to form guiding principles. These guiding principles would allow for the broader application of the solutions developed through the cycles.

3.3.2 Trustworthiness in the DBR process

At a basic level, DBR seeks to improve practice through a process of testing and refinement in a naturalistic setting and to derive from this process of refining practices, design principles that can be used by others in their settings. Therefore, it is essential that those who wish to use these design principles have a high degree of trust in the current research. Thomas and Magilvy (2011, p. 152) listed four aspects of trustworthiness: "(a) truth–value (credibility); (b) applicability (transferability); (c) consistency (dependability); and (d) neutrality (confirmability)." These are discussed below and summarised in Table 3.1.

Table 3.1
Rules of Conduct for the Investigation to Ensure Trustworthiness

Aspect of study	Tool/technique	Explanation
Data Collection	PBL Evaluation Tools	Administered by the researcher not used for assessment reporting. They were de-identified.
	Observations	Conducted by Head of Department and Laboratory Technician which the researcher would not be able to influence.
	Focus group interviews with students	Conducted by researcher's supervisors.
Credibility	Focus group interviews with students	Focus group interviews were conducted by the researcher's supervisors to minimise any potential dependent or unequal relationship.
	Sustained interaction with participants	The researcher is conscious of the importance of the need to be aware of any potential bias while working with the participants. Using a systematic approach that is fundamental to DBR regarding data collection and providing full details of its analysis reduces bias (Morrow, 2005).
	Member checking (Merriam, 1998)	The researcher transcribed the focus group interviews for review by the supervisors. The researcher also provided the participants with a transcript and asked for confirmation of transcript accuracy.
	Eidetic Bracketing (Gearing, 2004; Morrow, 2005; Tufford & Newman, 2012)	The researcher acknowledges the post-positivist point of view that the background and values of the researcher can affect observations. The researcher attempted to identify and set aside any biases that were identified and tried to approach the study in an unbiased way by, for example, reviewing literature that is both favourable and unfavourable to the theoretical framework for this study. The researcher examined and reviewed the data collected to ensure that any preconceptions or biases were made explicit.
	Triangulation	Data from different sources were collected using different individuals from the researcher's school and the University of Notre Dame Australia. The sources of data included the PBL Evaluation Tool results, observations and focus group interviews.

(continued)

Aspect of study	Tool/technique	Explanation
Transferability	Selection	The researcher provided a detailed description of the sample selected and the context of the study to allow the reader to decide how transferable the results are to other situations (Shenton, 2004).
Dependability		The methodology, including data collection methods and analysis, was described in such detail as to allow another researcher to repeat the study.
Confirmability	Audit trail	An audit trail shows how the data were collected and analysed during the study (Shenton, 2004).

3.3.2.1 Credibility

To be credible, a study must describe and explain all of the events in the study and the participants in that study would be in agreement with those descriptions and explanations (Krefting, 1991). In the current study, member checking and triangulation were used to ensure credibility. Thomas and Magilvy (2011) noted that comparing data from different sources and checking for consistency is a persuasive means of ensuring credibility. Member checking involves the participants in a study reviewing the data collected and (analysing) the interpretations of that data to ensure it reflects their own experiences (Krefting, 1991; Porter, 2007; Thomas & Magilvy, 2011) accurately. During this study, participants were given the opportunity during class to review responses made in the PBL Evaluation Tool and the focus group interviews. There was a review of the observations made during the lesson after each round of observations recorded. Triangulation was achieved by using data from different sources, collected using different individuals from the researcher’s school and the University of Notre Dame Australia. The sources of data included the PBL Evaluation Tool results, observations and focus group interviews.

Validity in predominately qualitative studies is an area of considerable debate. Golafshani (2003, p. 602) noted that “this concept [validity] is not a single, fixed or universal concept” in qualitative studies. Creswell and Miller (2000, p. 125) opined that “qualitative inquirers bring to their studies a different lens toward validity than that brought to traditional, quantitative studies.” To establish validity in a qualitative study Creswell and Miller (2000) linked validity to the methods used to show credibility of the data collected. These methods can include “member checking, triangulation, thick description, peer reviews, and external audits” (Creswell & Miller, 2000, p. 124). Member checking and triangulation were used in the current study.

3.3.2.2 Applicability

Applicability or transferability is “the ability to transfer research findings or methods from one group to another” (Thomas & Magilvy, 2011, p. 153). Both Krefting (1991) and Thomas and Magilvy (2011) noted the importance of providing a rich description of all aspects of the study so that others may replicate it in their unique situations. The current study provided such a rich description by specifying details of the methodology and analysis of the results.

3.3.2.3 Consistency

Consistency is a measure of how well the steps followed by the researcher could be tracked and understood by another person (Thomas & Magilvy, 2011) and “provides information as to how repeatable the study might be or how unique the situation” (Krefting, 1991, p. 221). Thomas and Magilvy (2011) noted that specifying the exact methodology of the research can show consistency and Krefting (1991) asserted that triangulation also contributes to consistency. This study used both processes. The procedure followed is outlined in this paper to ensure it can be replicated by other researchers and data were collected from different tools including the PBL Evaluation Tool results, observations and focus group interviews.

A consideration of reliability within qualitative research requires an alternate view of how to establish it in such a context. Noble and Smith (2015) assert that reliability in qualitative studies can be related to consistency and neutrality. Golafshani (2003) links reliability in quantitative research to consistency in qualitative research.

3.3.2.4 Neutrality

Neutrality is “the degree to which the findings of an inquiry are a function solely of respondents and the conditions of the inquiry and not of the biases, motivations, interests, perspectives, and so on, of the inquirer” (Guba & Lincoln, 1982, p. 246). Sale and Brazil (2004, p. 360) listed several strategies to achieve neutrality, including “Bracketing (Secker et al., 1995; Burns, 1989; Patton, 1999), statement of researcher’s assumptions (Marshall, 1990; Elliott et al.,1999) or statement of researcher’s perspective (Greenhalgh and Taylor, 1997).” Bracketing involves researchers in a process “whereby they recognize and set aside (but do not abandon) their a priori knowledge and assumptions, with the analytic goal of attending to the participants’ accounts with an open mind” (Starks & Brown Trinidad, 2007, p. 1376). Bracketing was made use of during the study by the researcher attempting to remain unbiased and seeking a neutral approach to reviewing the data collected in the study.

3.3.3 The role of the teacher/researcher in DBR

In this study, the teacher was also the researcher. Juuti and Lavonen (2006) stressed the importance of close collaboration and interaction between the researcher and the practitioner. The achievement of collaboration and interaction in this study occurred owing to the practitioner being the researcher. Cobb, Confrey, Lehrer, and Schauble (2003) accepted that a teacher might also be a researcher. Kelly (2003, p. 3) goes further by stating that DBR "is directed primarily at understanding learning and teaching processes when the researcher is active as an educator." Furthermore, Barab (2006, p. 153) stated that DBR "is used to study learning environments which are designed and systematically changed by the researcher." The teacher was in an appropriate position to effect such change in this study. This reinforced the dynamic nature of teaching where teachers constantly review their practice and modify it according to evidence collected.

3.3.4 Criticism of the DBR approach

To provide a balanced view of the DBR methodology, criticisms of the approach are considered and addressed. Kelly (2004, p. 116) stated that DBR needs to "develop design studies from a loose set of methods into a rigorous methodology" intimating that such a rigorous methodology does not currently exist. The assertion in this thesis is that Reeves' (2006) model mentioned earlier in this chapter addresses this concern. It is interesting to note that while McKenney and Reeves (2014, p. 133) stated that DBR "is not a methodology" nevertheless it is "held to the same standards as other scientific work." Another of Kelly's (2004, p. 119) claims was that DBR lacks an "argumentative grammar" which would be used, for example, to substantiate the collection of data and its subsequent use to develop credible theories. This lack of "argumentative grammar" is especially important given DBR's capacity to produce "unmanageable (and almost unstorable [*sic*]) amount(s) of data" (Dede, 2004, p. 107). Kelly (2004) also noted that "a simple assertion that design studies use 'grounded theory' or 'thick description'… does not constitute an acceptable basis for according design studies the status of a methodology.” (p. 119). While the current study produced large amounts of data, these data were in no way unmanageable or un-storable. Furthermore, in the current study, the use of the constant comparative method of qualitative analysis (Glaser, 1965) and eidetic bracketing (Gearing, 2004; Morrow, 2005; Tufford & Newman, 2012) addressed the concerns of a lack of argumentative grammar. However, The Design-Based Research Collective (2003) noted that when the intervention is in a naturalistic setting where the designer makes a large number of design decisions, it proves problematic to determine which ones are efficacious in bringing about any observed change. Such uncertainty leads to what has been termed the “Bartlett Effect” (Brown, 1992, p. 162) where only the data reported support the researcher’s claims. To provide an objective as possible interpretation of the data, the data were considered through the process of eidetic bracketing, where the “researcher [has] to set aside his or her personal assumptions” (Gearing, 2004, p. 1439). This was achieved in part by using external interviewers for the focus group interviews and independent observers for the Strobe Protocol to provide a data source to which the researchers own data could be compared. The statistical analysis of the quantitative data provided a means by which the researchers results could be validated dispassionately.

Some scepticism regarding the achievement of DBR’s goal of providing guiding principles applicable beyond the local context in which the study took place has been voiced by McKenney and Reeves (2013). However, they did acknowledge that the evidence for this scepticism may be a product of the assessment of this achievement, the lack of available data and the relatively recent arrival of DBR as a research methodology. The more studies conducted, the more data will be available, and a better judgement made of how DBR achieves its goal of providing guiding principles.

A final consideration was the Hawthorne Effect where changes in outcomes are owing to the subjects being studied rather than the intervention artefacts themselves (Merrett, 2006). However, Brown (1992) was quite dismissive of this effect where specific, rather than general, improvements were being investigated. Specific developments were the case in the current study where improvements in students' content knowledge and problem-solving ability in chemistry and physics were the focus.

3.3.5 The relevance of the DBR method

What does DBR have to offer that makes it an appropriate choice for the current study? In the current study, technology, in the form of e-textbooks, had a significant role in the creation of a PBL environment in the classroom. However, there has been a criticism of some research into the use of technology in educational settings including that it is "pseudoscientific and socially irresponsible" (Reeves, 2006, p. 52), lacking in a clear characterisation of the achievement of any reported gains. Furthermore, the design of technologies used in education is not based on research and may be "based on a designer's own experiences, and beliefs of effective learning or [the] design is purely technology driven" (Juuti & Lavonen, 2006, p. 55), which may adversely affect its adoption by educators.

DBR provides an effective means of investigating the use of technology in education because it involves a thorough investigation over a period of years from which derivation of principles for use in other situations occurs (Herrington, McKenney, Reeves, & Oliver, 2007). Juuti and Lavonen (2006, p. 54) noted that

DBR "bridge[s] the gap between educational research and praxis. It combines the designing of an educational artefact and research concerning the learning in the designed settings." As such, it could reduce the reluctance of educators to adopt new educational technologies, such as e-textbooks, since testing occurs in the naturalistic settings of a classroom. Finally, the use of DBR in doctoral research investigations (Bakker, 2004; Bower, 2008; Javed, 2008; Kazakoff, 2009; Kinnear, 2013; Nordin, 2012; Yeh, 2007) is indicative of its usefulness as an emerging research methodology.

3.4 Sample Population Selection

The school participating in the study is an independent day school situated in the City of Mandurah, located 70 km south of Perth. It is a secondary school and draws its students from both Mandurah and the surrounding districts. The school has an Index of Community Socio-Educational Advantage (ICSEA) rating slightly above average with most students in the middle quarters (Table 3.2). The school places a strong emphasis on academic success and students from the school consistently perform well in the Western Australian Certificate of Education examinations each year. The school has specialist computer laboratories, an ICT service department and a 1:1 laptop ratio in years nine to twelve.

Table 3.2
Statistical Data for the School Where the Study Took Place (ACARA, 2012)

Student background

Index of Community Socio-Educational Advantage (ICSEA)	
School ICSEA value	1070
Average ICSEA value	1000
Data source	Parent information

Distribution of students [2]

	Bottom quarter	Middle quarters		Top quarter
School Distribution	5%	29%	37%	29%
Australian Distribution	25%	25%	25%	25%

Percentages are rounded and may not add to 100

Students

Total enrolments	1291
Girls	681
Boys	610
Full-time equivalent enrolments ?	1291
Indigenous students	1%
Language background other than English	6%
Student attendance rate	95%

School facts

School sector	Non-government
School type	Combined
Year range	U, PP-12
Location	Provincial

The school determined the classes and subjects taught by the researcher. The Year 10 classes typically numbered from 25 to 30 students who complete six periods of Science per week. These periods were usually 40 minutes long and consisted of two double periods and two single periods. Each class was heterogeneous in semester one, but streaming occurred in semester two with the top 45% of students being placed together in an accelerated program. The remainder, which was the group used in this study, completed a general science course. The streaming policy changed in 2015 with all Year 10 classes remaining heterogeneous.

3.5 Conduct of the Cycles

There were three cycles conducted over three years, 2013, 2015 and 2016. The first cycle was used to gain a sense of the educational environment, including determining any logistical problems with regard to the use of the e-textbook technology and the students' interactions with it. The cycles outlined in Table 3.3 were used to trial new strategies and techniques based on a review of the preceding iterations.

Table 3.3
Students Involved in the Current Study

Cycles	Iteration topics	Topic length (weeks)	Class size		
			Number of students	Number of groups	Number of students who permitted results to be used in this study and participated in focus group interviews
Cycle one (2 classes)	Iteration 1 Newton's Laws Iteration 2 Chemical Reactions	5 6	20 and 25	5 and 6	7 and 17
Cycle two	Iteration 1 Newton's Laws Iteration 2 Compression and Tension	6 5	28	6	12
Cycle three	Iteration 1 Newton's Laws Iteration 2 Chemical Reactions	6 6	19	5	11

3.5.1 Cycle one

The first cycle was conducted in the second semester of 2013 with two Year 10 classes participating in two iterations. The two Year 10 classes were heterogeneous groupings of middle ability students. The Year 10 classes studied two subjects using e-textbook and PBL: physics and chemistry. The physics unit covered Newton's Laws of Motion and sought to apply those laws to the design of a model rocket. The chemistry unit covered different types of reactions and the factors that affect the rate of reactions. The researcher designed the e-textbook using Adobe InDesign™. The design of the e-textbook was changed slightly in the second iteration, the Chemical Reactions topic, in response to some difficulties experienced by the students with the first e-textbook. Specifically, the problem was broken down into a series of smaller problems with one large problem at the end.

3.5.2 Cycle two

Cycle two was conducted in 2015 in semesters one and two with two iterations. The Year 10 class was a heterogeneous grouping of students with varying ability levels. The Year 10 class studied two subjects using e-textbook and PBL: physics and structures. The physics unit covered Newton's three laws of motion in a series of problems and then sought to apply those laws to the design of a model rocket as the final problem. The structures unit covered compression and tension. The design of the e-textbook changed in the second cycle in response to difficulties experienced with the first e-textbook. The changes involved using a new platform to produce the e-textbook and improve the presentation of the problems to the students.

3.5.3 Cycle three

Cycle three was conducted in 2016 in semester one and two with two iterations. The Year 10 class was a heterogeneous grouping of students with varying ability levels. The Year 10 class studied two subjects using e-textbook and PBL: physics and chemistry. The physics unit covered Newton's three laws of motion in a series of problems and then sought to apply those laws to the design of a model rocket as the final problem. The chemistry unit covered different types of reactions and the factors that affect the rate of reactions. The design of the e-textbook changed in the third cycle in response to some difficulties experienced by the students with the previous e-textbook. In particular, students received more support and problem presentation and navigation improved.

3.6 The Instruments Used in the Study

The study was predominately qualitative, which is defined as a type of research that Malterud (2001, p. 483)noted "involve[s] the systematic collection, organisation, and interpretation of textual material derived from talk or observation." Curry, Nembhard, and Bradley (2009, p. 1442)added that "they are often exploratory in nature and seek to generate novel insights using inductive … approaches." Wang and Hannafin (2005, p. 17) noted that "qualitative documentation methods are often especially useful in design-based research." The qualitative aspects of this study included observations of classes, focus group interviews and three pre- and post-PBL Evaluation Tools. Quantitative aspects of this study were pre- and post-knowledge tests for each topic in the PBL Evaluation Tool. The use of some quantitative data with qualitative data "can achieve various aims, including corroborating findings, generating more complete data, and using results from 1 method to enhance insights attained with the complementary method" (Curry et al., 2009, p. 1442). Table 3.4 details the relationship between the data collection methods and the research questions.

Table 3.4
The Relationship Between the Research Questions and the Data Collection Method with Possible Interpretations Made from the Data

Research question	Data collection instruments	Data interpretation	Collection dates
1. What constraints (if any) inhibited the implementation of the e-textbook supported PBL intervention?	Weekly observation during problem-solving tasks conducted by independent observers Focus group interview at the conclusion of each iteration	Observation data can determine: (i) if most students are on task; (ii) what individual students are doing; (iii) what groups of students are doing; (iv) what the teacher is doing.	2013 (Cycle 1) 2015 (Cycle 2) 2016 (Cycle 3)
2. What design features of the e-textbook supported PBL intervention most influenced student learning?	Weekly observation during problem-solving tasks conducted by independent observers Focus group interview at the conclusion of each iteration	From this, identification of factors constraining the e-textbook supported PBL intervention, and design features of this intervention that most influenced student learning.	2013 (Cycle 1) 2015 (Cycle 2) 2016 (Cycle 3)
3. What was the overall impact of the e-textbook supported PBL intervention in terms of students': - content knowledge; - problem-solving skills; - transfer of content knowledge to other topics.	Pre- and post- PBL Evaluation Tools Focus group interview at the conclusion of each iteration	The tools help to determine if there has been an improvement in student achievement by comparing student results before each iteration to those after each iteration.	2013 (Cycle 1) 2015 (Cycle 2) 2016 (Cycle 3)

3.6.1 PBL Evaluation Tool

The main focus of this study was the use of e-textbooks to facilitate PBL in secondary school science students. The PBL Evaluation Tool (Pre and Post) was used to consider if there was an improvement in the students learning when using e-textbooks to support PBL (Appendix five). The instruments described in Table 3.4 provided useful data upon which to consider any improvement in the students' learning when using e-textbooks to support PBL.

While not the only aspect of PBL environment, solving problems is an important component of the process (Anderson & Lawton, 2014; DeWaters & Powers, 2011; Jonassen, 2011; Schmidt et al., 2011; Yeo & Tan, 2014). Gijbels, Dochy, et al. (2005, pp. 34–35) distilled two characteristics of expert problem solvers from cognitive psychological research:

> Experts possess coherent knowledge. They have command of a well-structured network of concepts and principles in the domain that accurately represents key phenomena and their relationships;
> Experts know how to use the relevant elements of knowledge in a flexible way to describe and solve novel problems. (p. 30)

These characteristics provide a benchmark to compare against students engaged in problem-solving using the eight tasks described by Newman (2005):

- Explore the problem: clarify terms and concepts that are not understandable, create hypotheses, identify issues;
- Identify what you know already that is pertinent;
- Identify what you do not know;
- As a group, prioritize the learning needs, set learning goals and objectives, allocate resources; members identify which task they will do;
- Engage in a self-directed search for knowledge;
- Return to the group and share your new knowledge effectively so that all group members learn the information;
- Apply the knowledge; try to integrate the knowledge acquired into a comprehensive explanation and;
- Reflect on what has been learned and the process of learning. (p. 15)

Several criteria may be used to assess problem-solving in relation to evaluating knowledge structure. Sugrue (1994) and Gijbels, Dochy, et al. (2005, pp. 34–35) identified three criteria: understanding of concepts, understanding of principles and application of those concepts and principles. Gijbels, Dochy, et al. (2005) provided a useful matrix, based on the first part of Sugrue's (1995) own matrix for assessing knowledge structure. Importantly Gijbels, Dochy, et al. (2005, p. 35) noted that the type of assessment, multiple choice, open-ended or hands-on format, was not as important as measuring "the extent to which the student's knowledge structure is organized around key concepts and principles that are linked to conditions and procedures for application." In this study, Sugrue's (1994) original matrix was useful for assessing problem-solving, which included metacognition and motivation since these are important attributes of a problem solver.

A number of metacognitive strategies are available within the context of using e-textbooks to facilitate PBL in students. These strategies are described broadly by Nett, Goetz, Hall, and Frenzel (2012, p. 1) and Sugrue (1995, p. 30) as "planning", "monitoring" and "evaluation." The aspects of motivation relevant in this study were described by Green et al. (2012, p. 1113) and Sugrue (1995, p. 30) as self-efficacy, by Lai (2011, p. 7) as task difficulty and as task attractiveness by Pintrich and De Groot (1990, p. 33), Sugrue (1995, p. 30) and Wigfield and Eccles (2000, p. 68).

The final question to be answered was how to apply these measurements to Newman's (2005) eight PBL tasks. A new matrix was developed to include the tasks, where appropriate, in Table 3.5 to achieve this. It was not possible to find a complete correlation between all of the items in Sugrue's matrix (1994) and Newman's (2005) tasks. However, the inclusion of all of the tasks occurred at least once. Pre- and post-evaluation was used to determine changes in students' problem-solving ability. The first two research questions: What constraints (if any) inhibited the implementation of the e-textbook supported PBL intervention? and What design features of the e-textbook supported PBL intervention most influenced student learning? were to be answered through the DBR iterative process.

Table 3.5
A Design Matrix Incorporating the Criteria of Gijbels, Dochy, et al. (2005); (Newman, 2005; Sugrue, 1995) to Assess Learning in a PBL Environment

	Elements of knowledge structure, metacognitive function and motivation	Method					
		Selection		Generation		Explanation	
		(Sugrue, 1995) and (Gijbels, Dochy, et al., 2005)	(Newman, 2005)	(Sugrue, 1995) and (Gijbels, Dochy, et al., 2005)	(Newman, 2005)	(Sugrue, 1995) and (Gijbels, Dochy, et al., 2005)	(Newman, 2005)
Knowledge structure	Concepts	Select examples		Generate examples	Identify what you know already that is pertinent. Identify what you do not know.	Explain why examples reflect concept attributes. Select live examples.	Explore the problem: clarify terms and concepts that are not understandable, create hypotheses and identify issues.
	Principles	Select best prediction Select best explanation	Explore the problem: identify issues	Generate predictions or solutions. Explain an event		Explain predictions or solutions	
	Application conditions and procedures	Select correct procedure for identifying instances. Select most appropriate procedure to change the state of a concept by manipulating another concept.	Identify what you know already that is pertinent. Identify what you do not know.	Perform task specific procedures. Generate (describe) a procedure.	As a group, prioritise the learning needs, set learning goals and objectives and allocate resources; members identify which task they will do.	Explain how to perform a procedure	Return to the group and share your new knowledge effectively so that all group members learn the information. Apply the knowledge: try to integrate the knowledge acquired into a comprehensive explanation.
Metacognitive function	Planning	Select or rate items that represent amount and type of planning engaged in during the activity	As a group, prioritise the learning needs, set learning goals and objectives and allocate resources; members identify which task they will do.	Engage in behaviours indicative of planning during the activity.	Engage in a self-directed search for knowledge.	Describe amount and type of planning engaged in during activities.	

(continued)

	Elements of knowledge structure, metacognitive function and motivation	Method					
		Selection		Generation		Explanation	
		(Sugrue, 1995) and (Gijbels, Dochy, et al., 2005)	(Newman, 2005)	(Sugrue, 1995) and (Gijbels, Dochy, et al., 2005)	(Newman, 2005)	(Sugrue, 1995) and (Gijbels, Dochy, et al., 2005)	(Newman, 2005)
	Monitoring	Select or rate items that represent amount and type of monitoring engaged in during the activity.		Engage in behaviours indicative of monitoring during the activity.		Describe amount and type of monitoring engaged in during activities.	Reflect on what has been learned and the process of learning.
	Perceived self-efficacy	Select or rate items that represent level of confidence in ability to do well on different activities.		Engage in behaviours indicative of effort and persistence during the activity.	Set learning goals and objectives and allocate resources; members identify which task they will do.	Describe one's perception of one's ability to do well on different activities.	Reflect on what has been learned and the process of learning.
Motivation	Perceived task difficulty	Select or rate items that represent perceived relative difficulty of different activities.		Engage in behaviours indicative of effort and persistence during the activity.	Engage in a self-directed search for knowledge.	Describe one's perception of the relative difficulty of different activities.	Reflect on what has been learned and the process of learning.
	Perceived task attraction	Select or rate items that represent perceived relative attraction of different activities.		Engage in behaviours indicative of effort and persistence during the activity.		Describe one's perception of the relative attraction of different activities.	Reflect on what has been learned and the process of learning.

3.6.2 Strobe observations

Applying assessment items to each of the criteria in Table 3.5 informed the third research question: What was the overall impact of the e-textbook supported PBL intervention. Observation is considered a useful tool for providing information about the activities of others or their response to various experiences (Jones & Somekh, 2005; McMurray, Scott, & Pace, 2004). Natural observation, with observations made in realistic environments, are useful in collecting information about group behaviour (McMurray et al., 2004), which was the focus of the current study. The PBL groups were observed via the Strobe Protocol described by Kelly et al. (2005). The Strobe Protocol was initially developed by O'Malley et al. (2003) to provide a means of documenting student engagement during a lesson although an antecedent of the protocol was described by Marchant (1989).

The Strobe Protocol was chosen for the current study because it provided a large amount of information about what was occurring in the classroom, including the: level of student engagement, type of student work and teacher interactions in a relatively unobtrusive way. O'Malley et al. (2003, p. 100) found that the Strobe Protocol provides "a practical, reliable, and valid instrument" for measuring the behaviour of students. The Strobe Protocol has been used successfully in undergraduate studies (D'Souza, Isac, Venkatesaperumal, Nairy, & Amirtharaj, 2013; Hurford & Hamilton, 2008; Ofstad & Brunner, 2013) and secondary school courses (Seaton & Carr, 2005), which demonstrates its usefulness. McMurray et al. (2004) listed, among other considerations, three important steps when using observation as a data gathering tool:

- Decide how many observations to make;
- Decide how long to observe;
- Decide what to observe. (p. 194)

In the current study, a reporting sheet modified from Fermilab (2013) took into account these three considerations of how many observations, how long and what to observe. The recording sheet for the Strobe Protocol was modified to make it easier for the observer to make and record observations with minimal training. Appendix three details the modified Strobe Protocol recording sheet.

3.6.3 Informal classroom observations

Observation refers to “the purposeful examination of teaching and/or learning events through systematic processes of data collection and analysis” (Bailey, 2001, p. 114). Tilstone (2012, p. 23) described observation as “the systematic, and as accurate as possible, collection of usually visual evidence, leading to informed judgements and necessary changes to accepted practices.” This study used a qualitative approach to informal classroom observation. O'Leary (2014) listed three types of qualitative observations:

- Completely unstructured, ‘stream of consciousness’ type where the observer is given a blank canvas to record their notes as a ‘running log’ of events;
- Semi-structured type where what the observer records is shaped by a set of pre-established categories; and,
- Highly structured type, which shares many of the features of the previous type but divides assessment of the lesson into individual performance indicators. (p. 54)

The first type of observation provided to the observer, in this case, the researcher, no guidance as to what to observe, which had the advantage of not prejudicing the observer to produce a particular outcome. Wragg (1999) noted that while quantitative methods allow observations to focus on particular events according to predetermined criteria, it is less adaptable regarding recording what is happening in the classroom. The current study used this running log model to make observations because it was the most flexible.

The researcher entered observations into a journal at the end of each lesson. The entries reflected on how the lesson progressed and noted any difficulties and successes of individual students, groups and the use of the e-textbook. The interactions between the teacher/observer and the students were also noted.

In this study, the qualitative informal classroom observations were complemented by the Strobe Protocol. The Strobe Protocol provided a quantitative comparison made by independent observers, the school laboratory technician and the head of the Science Department, to the qualitative informal classroom observations. Wragg (1999, p. 20) noted that "quantitative and qualitative approaches need not be seen as polar opposites, as they can often complement each other."

3.6.4 Focus group interviews

At the conclusion of each PBL activity, a focus group of volunteers from each class convened. Onwuegbuzie, Leech, and Collins (2010, p. 711) defined focus groups "as a method of collecting data, in a safe environment, from more than one individual at a time, regarding a specified area of interrogation." Onwuegbuzie, Dickinson, Leech, and Zoran (2009) described some advantages in using focus groups, including efficiency and increased data generation through social interaction. The questions were developed from observations made during the PBL task and follow guidelines proposed by McMurray et al. (2004), who suggested that there should be "opening questions", "framing questions", "focal questions" and "concluding questions" (p. 204). Opening questions were covered informally by the facilitators asking the names of the students. Questions followed that framed the topic, which was PBL and the use of e-textbooks. The remaining questions focused on specific aspects of the students' experiences. To conclude, the interviewer asked students if they had any further comments or questions. Appendix four details the focus questions asked. Each class provided volunteers for the focus group interviews with the final selection of those to be involved based on having a range of students from groups that performed well on the task as well as those who performed adequately and poorly, based on observations during the iteration. The size of the groups ranged between five and six people.

3.7 Development of Problems

Table 3.6 details the specific problems used in the current study. In selecting the problems in Table 3.6, a range of factors needed consideration: context, structuredness and abstractness. Each problem type is presented against the factors that describe it.

Table 3.6
Aspects of the Problems Used in the Current Study Incorporating Jonassen's Criteria (Jonassen, 2000)

Problem type	Problem example	Australian curriculum link	Inputs	Success criteria	Context	Structuredness	Abstractness
Rule using	Compression and Tension	ACTDEK043	Application of compression and tension to building structures	Correct application of the rules to a novel situation	Real world	Multiple solution paths. Defined purpose	Problem situated
Troubleshooting	Reaction rates	ACSSU187	Inefficient production of chemical product owing to poor setup	Fault identified and rectified	Real world	Limited faults and outcomes	Problem situated
Design	Newton's Laws	ACSSU229	Goal: improve design of rocket Constraints: Max altitude 75 m; payload 100 g; available materials Structure: initial rocket design	Improved rocket performance	Complex Real world	Ill-structured	Problem situated

The context within which a problem exists is important since the skill set that a student will use to solve a particular problem is specific to the context of the problem (Jonassen, 2000). Context is also important in representing the problem to the intended audience, in this case, secondary school students. Walker and Leary (2009) noted that the importance of context varies with the degree of structuredness in the problem, with the context in ill-structured problems being vitally important. However, Jonassen (2000) stated that exceptions exist to this rule of context varying with structuredness. Jonassen (2000), differentiated between the type of strategies that are used to solve these problems, asserting that, in general, structured problems require only “domain-general strategies (weak methods)” (p. 68). This study asserts that most secondary school problems within the science area, in fact, require specific problem-solving strategies that would be context dependent, and therefore, context is important. Therefore, it was important to establish a clear context for each problem in the current study so that students could learn and use a specific skill set to effect a solution.

The structuredness of a problem relates to how many elements are known, the number of possible solutions, how identifiable the solutions are and whether value judgements need to be made (Jonassen, 2000). These decisions are not discrete, but rather, exist along a continuum. The continuum in Figure 3.2 represents the structuredness of a problem.

Figure 3.2. A continuum of problem structuredness based on Jonassen’s criteria (Jonassen, 2000).

In deciding how much structure to put into a problem, Hung (2006) noted the importance of the problem-solving ability of the learning as a determining factor, with students less able to problem solve requiring more structure. In the current study, students were assumed to have limited problem-solving ability at the start of the year owing to the minimal exposure they have had to PBL environments, and so, initially, the problems were quite structured. However, the level of structuredness reduced as the year progressed and students became more familiar with PBL environments. As mentioned earlier, most secondary school problems are considered abstract, given that they have no situational context (Jonassen, 2000). However, within science PBL environments it is argued, in the current study, that these problems do require a context to allow for the application of specific skills and as such are not abstract.

3.8 Methods of Data Analysis

Pre- and post-PBL Evaluation Tool data were compared by determining mean scores for each criterion and calculating standard deviations. A Wilcoxon signed-rank test was used to determine if there was a significant change in the scores since the sample is small and may not be normally distributed. Qualitative data were analysed using NVivo™ to code the student responses to the intervention tools and the focus group interviews. In each case student responses were reviewed, and broad categories developed into which their responses were coded. Descriptions of each category were included in the NVivo™ program which allowed for consistency of coding over the study period. The constant comparative method of qualitative analysis (Glaser, 1965) was used to code the qualitative data. This method is "a central data collection method in the grounded theory methodology…[and] provides a clear step by step outline of a process for analysing qualitative data" (Case & Light, 2011, p. 193). Strauss and Corbin (1994) noted that grounded theory allows for the development of a theory from the data rather than relying on the data to support the theory. The theory was congruent with the DBR methodology, which developed applicable theories at the end of the process rather than affirm theories at the start.

Table 3.1 summarises the procedures used to ensure the integrity of the data collected.

3.9 Software

The software used to produce the e-textbooks in this study was InDesign CS6™, Flash™ and Mediator 9™. InDesign CS6™ was used to produce the first e-textbook since it provided a way of combining various features, including video and text, into a single presentation for students to use. However, there were limitations to the use of InDesign CS6™ that made it unsuitable for future cycles. In cycles two and three, Flash™ and Mediator 9™ were used. Mediator 9™ was used as the platform to construct the e-textbook because it provided a way of combining most of the interactive features required for this study in one package. It was augmented by Flash™ to provide extra animation when required.

3.10 Limitations

There were limitations to this study that included the sample size, the subject and topics covered and the length of the intervention. Limitations of sample size and subject were owing to the allocation, by the school, of classes to the teacher. Teachers can only teach in their area of expertise and only to classes assigned by the Head of Department in the School. The Australian National Curriculum limited the number and length (five to six weeks) of topics in the study. However, it was possible to view some of those limitations as strengths of the study rather than weaknesses since they fit well with the DBR process of researching natural environments. Juuti and Lavonen (2006) described the complex milieu that is the science classroom and noted that it does not readily lend itself to standard scientific investigation but does suit a DBR process. Nevertheless, the study occurred in only one school, which will limit any generalisations.

3.11 Ethical Considerations

The researcher attempted to be dispassionate, unbiased and open-minded about the study and was committed to objectively reporting the findings. Triangulation through using data from different sources collected using different individuals from the researcher's school and the University supervisors were used to ensure this objectivity. The sources of data included the PBL Evaluation Tool results, observations and focus group interviews. Table 3.1 highlights the rules of conduct that were used to ensure researcher bias was minimised while also improving the study's trustworthiness, namely credibility, transferability, dependability and confirmability (Guba & Lincoln, 1982, p. 246).

Consideration also needs to be given to the power differential between the teacher/researcher and the students in the classroom. The latter were given the option to withdraw from the study at any time without prejudice. This option was included in the letter of consent they signed. Therefore, the students had the power to remove themselves from the study if they felt pressured or uncomfortable at any stage.

3.12 Summary

The use of predominately qualitative instruments was consistent with the pragmatist paradigm that was most suited to the current study. A DBR methodology with three cycles, each consisting of two iterations, reviewed through a lens of pragmatism provided a suitable research setting. The sample for the current study consisted of four Year 10 classes (2025 students per class) sourced from the researcher's school. Data collection was in the form of observations, focus group interviews and evaluation tools. The data were analysed using a Wilcoxon signed-rank test and NVivo 10™ software to code student responses.

A variety of instruments were used in this study to evaluate the students' learning of the content presented in the e-textbook and included PBL Evaluation Tool, focus group interviews, informal classroom observations and structured observations. These instruments were used to provide some different sources to answer the research questions. It was not the intention to determine definitive answers, but rather, to provide information that would allow for the refinement and further development of the e-textbooks for the second and third cycles.

The PBL Evaluation Tool was designed to capture information regarding the students' content knowledge of the subject, their metacognitive abilities and their motivation to complete the task at hand. The PBL Evaluation Tool was administered immediately before each iteration and again at its conclusion. While the need to assess changes in student content knowledge was self-evident and the methodology well established, the other two aspects of the PBL Evaluation Tool required further elaboration.

The focus group interviews were designed to provide the students' perspective on each iteration to the researcher. The students' responses were used to determine the effectiveness of the intervention regarding the design of e-textbooks, the e-textbooks effect on their learning and difficulties experienced by students using the e-textbooks. This information could then be used to inform future developments of the e-textbooks and extrapolated to introducing PBL in a wider setting. Informal classroom and structured observations were performed by the researcher and by an independent observer respectively. They intended to identify implementation difficulties during the PBL intervention, levels of student engagement with the tasks and, in the long term, the implications for a wider use of PBL in the classroom.

The analysis of these various instruments included a Wilcoxon Signed Rank two-tail test for paired samples and Spearman–Brown split-half reliability coefficient. Student responses' in the PBL Evaluation Tools and focus group interviews were coded into categories using NVivo 10™ based on the students' answers to the questions posed. Transcription of informal classroom observations occurred at the end of each lesson.