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

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Chapter Six: Cycle Three—Results, Review and Implications

6.1 Introduction

"It is good to have an end to journey toward; but it is the journey that matters, in the end" (Le Giun, 1969, p. 220). Cycle three was the final step on a journey to answer the three important questions regarding the use of e-textbooks to support Problem-Based Learning (PBL) in secondary school science classrooms and, in doing so, finding a destination by reflecting on the journey. These questions related to e-textbook supported PBL iterations and are concerned with their design features, their impact on students and the constraints in using them in secondary schools. This chapter will recapitulate the analysis of cycle two and then present the results and analysis of cycle three.

6.2 A Recapitulation of Cycle Two

The completion of the second cycle provided a basis for the further refinement of the e-textbooks and their use to support PBL in science classrooms. Evaluation tools, interviews and observations were used to acquire information that allowed for some implications for the design of e-textbooks and their use in PBL. These implications concerned scaffolding problem-solving and group-work, providing feedback on progress, engendering a greater appreciation of practical work and helping students see the value of problem-solving.

6.3 The Cycle Three Environment

Cycle three involved one Year 10 Science class and covered two topics: Newton's Laws and Chemical Reactions. Eighteen students comprised the class of which 10 participated in the study with the permission of their parents. Each topic lasted five weeks, and each was a topic covered by Year 10 students as part of the Australian National Science Curriculum. The 18 students in the class were part of the mainstream cohort that comprised 93% of the year cohort, and selection occurred by achieving a combined score on tests and an examination of not less than 34%. The remaining 7% were moved to other classes since this was the policy of the Science Department at the School at the time of this third cycle. There were four lessons per week consisting of two 80-minute periods and two 40-minute periods. The students worked on the problems in science laboratories where standard scientific equipment was available to them. Each student had access to a laptop from which they worked with the e-textbook in groups of four or five individuals.

6.4 Themes Arising from the Analysis of the Data

The analysis of the data from the two iterations of cycle three revealed 15 different themes related to the research questions that this study attempted to answer. Table 6.1 presents the research questions, the data and the themes that arose from the data's analysis. There follows an analysis of each theme in relation to each research question.

Table 6.1
A Summary of the Themes Identified in the Data from Student Responses by Research Question

Research question	Themes	Data collection component	Data source in appendix A1.1 and A1.2
1. What constraints (if any) inhibited the implementation of the e-textbook supported PBL intervention?	Function of e-textbook	FGI NL3	Questions 1 & 7
	Functionality of e-textbook	FGI NL3	Question 7
		ICO	17/08
	Technology infrastructure	FGI NL3	Questions 3, 6 & 7
		FGI CR3	Question 1
		ICO	17/5, 13/06 & 15/08
	Understanding PBL	FGI NL3	Question 1
	Note-taking	FGI NL3	Questions 7 & 9
		FGI CR3	Question 4
2. What design features of the e-textbook supported PBL intervention most influenced student learning?	Multimodal	FGI NL3	Questions 7 & 8
		FGI CR3	Question 7
		ICO	All
	Group-work	FGI NL3	Question 6
		FGI CR3	Questions 2, 3 & 6
	Enjoyment	ICO	All
		PBLETSE	Table A1.16 & Table A1.38
	PBL	FGI NL3	Questions 2 & 4
		FGI CR3	Questions 1 & 4
		ICO	All
	Hands-on	FGI CR3	Questions 1, 3 & 4
		PBLETSE	Table A1.16 & Table A1.38
	Argumentation	ICO	26/05, 30/05, 31/05, 9/08, 11/08, 18/08 & 24/08

(continued)

Research question	Themes	Data collection component	Data source in appendix A1.1 and A1.2
3. What was the overall impact of the e-textbook supported PBL intervention?	Content knowledge and its application	FGI NL3	Questions 3 & 4
		PBLETK	Figure A1.3, Figure A1.17, Table A1.1, Table A1.2, Table A1.3, Table A1.4, Table A1.6, Table A1.24, Table A1.25, Table A1.26, Table A1.27, Table A1.28 & Table A1.30
	Misconceptions	FGIETK	Table A1.1, Table A1.2, Table A1.4, Table A1.6, Table A1.24, Table A1.25 & Table A1.28
	Planning, monitoring & evaluation	FGI NL3	Question 2
		FGI CR3	Question 6
		PBLETK	Table A1.5
		PBLETMPE	Table A1.9, Table A1.11, Table A1.12, Table A1.34 & Table A1.33
	Student engagement	PBLETSE	Table A1.11, Table A1.13, Table A1.14, Table A1.15, Table A1.16 , Table A1.7. Table A1.35, Table A1.36, Table A1.37, Table A1.38 & Table A1.39
	Hard-scaffolding	SPO	Table A1.23 & Table A1.42
		FGI NL3	Question 2

Note. FGI NL3 refers to focus group interview—Newton's Laws, FGI CR3 refers to focus group interview—Chemical Reactions; ICO refers to Informal Classroom Observation, SPO refers to Strobe Protocol Observations, PBLETK refers to PBL Evaluation Tool, Knowledge, PBLETPME refers to PBL Evaluation Tool, Planning, monitoring and evaluation and PBLETSE refers to PBL Evaluation Tool, Student engagement.

6.4.1 Themes relating to research question one arising from the analysis of the data: constraints

Cycle three of the iteration revealed several themes about the constraints that inhibited the implementation of an e-textbook supported PBL intervention. These themes included:

- function of e-textbook
- functionality of e-textbook
- technology infrastructure
- understanding PBL
- note-taking.

It was possible to group these themes into three broad categories that could be considered together owing to the similar underlying characteristics.

6.4.1.1 Learning constraints

This category included any factors that affected the students' acquisition of knowledge and skills. These factors related to constraints that the students should have been able to mitigate through their actions or interactions, but which they did not do for various reasons. There was only one factor that related to learning constraints in this iteration. Table 6.2 details these categories.

Table 6.2
Themes Contained in Each Category for Research Question One

Categories	Themes
Learning constraints	Function of e-textbook
Pedagogical constraints	Understanding PBL
Technical constraints	Technology infrastructure Functionality of e-textbook Note-taking

6.4.1.1.1 Function of the e-textbook

The e-textbook was designed to facilitate PBL for the students using it and not as a digitised traditional textbook that they use in science. This mismatch created a disequilibrium in the students using the e-textbook. When asked in the focus group interview about the e-textbook, one student stated that “it’s a lot easier to have a physical textbook that you can flick through the pages and often there is a lot more information there” (FGI NL3 S3). The lack of information in the e-textbook was commented on by two other students in the interview in response to the same question. When asked about learning the content regarding Newton’s Laws, one student noted that “I just think like overall I liked the e-book but if it was more in-depth” (FGI NL3 S5). The students had a preconceived idea that the ‘textbook’ should provide all the answers to a problem without them having to do any extra work. This issue did appear in the Chemical Reactions iteration, but to a lesser extent, perhaps because the students were now used to the idea that the e-textbook was not there to provide them with the answers. However, one student did comment in the Chemical Reactions focus group interview that:

> I do like the normal textbook a lot because like you have the-the topics like the chemistry topic. And then let’s say we’re talking about co-covalent bonds or something, there’s a topic of that in that chapter and you—everything that you need to know about it is there with the diagrams and everything. (FGI CR3 S1)

Thus, while the issue of the e-textbook not providing all the information to students has abated somewhat, it was still extant in some students’ minds. However, it was possible to postulate that further exposure to the e-textbook PBL format would continue to have a positive impact on students’ expectations of it. In particular, they would more likely became better accustomed to the PBL process.

6.4.1.2 Pedagogical constraints

Pedagogical constraints were outside the direct sphere of influence of students and therefore beyond their immediate control. This inability of the learner to directly influence these factors delineates the pedagogical constraints discussed below from learning constraints. There was only one factor that related to pedagogical constraints in this iteration.

6.4.1.2.1 Understanding PBL

The student responses in the focus group interview conducted after the Newton's Laws iteration highlighted the issues around not understanding the purpose of PBL. When asked what they liked or disliked about the topic, one student noted that:

> I disliked how the experiments we did the results we got from them were difficult to get accurate because of how the tests were set-up. Like we had one where you had to attach a balloon to a string and run the balloon down the string as to test I think the force of the balloon but the problem with that is the balloon has a variable weight depending on how much air is left in it so you can't get an immediately accurate result so I think it would be better if the experiments we did we could gain a lot more exact results that are easier to understand rather than running an experiment and getting more rough results from that. (FGI NL3 S3)

This response highlighted a few issues regarding PBL in this iteration. The problems were deliberately ill structured, and the concerns the student was raising are ones that they needed to solve this problem. The student was aware of the issues, but not able to go to the next step of trying to resolve them. The student wanted more exact results but did not try to develop a means of achieving those results. Another student's response was more direct in delineating one of the issues:

> I thought that it was hard to understand what to do for the experiments coz [*sic*] obviously, we had to design them ourselves, but most of us were stuck

> on like how to start off – like we got the materials, but we couldn't figure it out. (FGI NL3 S1)

In this case, the student was not able to start working on the problem without some help and so would take longer to appreciate the most intricate issues in the problem. For example, obtaining reliable results while considering several factors that could affect those results.

However, this sentiment was not universal among the students in the focus group interview. Another student stated that "I kind of liked how like not knowing because it makes you feel like more independent. I just liked that bit." (FGI NL3 S4). The preference for independent problem-solving carried over into the Chemical Reactions iteration where the students did not express the same issues with working on the problems. One student in the Chemical Reactions focus group interview noted that:

> It felt more worthwhile learning it than rather than just taking down some notes and going Oh, I've learned this for a test. When you're actually doing it, you go I've actually learned something now, like you now apply it. (FGI CR3 S5)

There was a realisation among the students of the purpose of PBL, and thus, there was less resistance to working on ill-structured problems for which they had no immediate solution. There was also a perception that it was possible to learn while working on a problem and that solving the problem was a part of the learning process. This perception was evident from the informal classroom observations (Table A1.41) and the Strobe observations (Table A1.42) where students were on-task in working with the problem and the facilitator was interacting with subgroups about specific issues related to the problems.

6.4.1.3 Technical constraints

Technical constraints were also outside the students' sphere of influence and control. However, their source and therefore the measures needed to mitigate them were different. As such, they needed to be considered separately from the pedagogical constraints. Three technical constraints occurred in this cycle.

6.4.1.3.1 Technology infrastructure

The issues centred around accessing the e-textbook during the lesson. In the focus group interview for Newton's Laws, students expressed their frustration:

> I thought it was worse coz [*sic*] the process of having to open a laptop and connect to VMWare, a lot of people take a lot of time doing that and then having the program open some people had to go to IT multiple times to get it to work properly. (FGI NL3 S3)
>
> It was really good like I really liked it except the fact that logging onto it took a lot of time, like if it was a book you would just open it and get on with it. (FGI NL3 S2)
>
> I think that is the schools Wi-Fi though coz [*sic*] the schools Wi-Fi kind of affected that a lot. (FGI NL3 S5)

There were clearly issues with the technology infrastructure, and this had a significant impact on how the students were able to access and interact with the e-textbook. This issue repeated itself in the Chemical Reactions iteration focus group interviews where students again raised issues concerning access to their e-textbooks:

> The only thing I could see that I didn't like about it would be just the, uh, multiple IT problems we were having… Like it wasn't the eBook itself; it was just the computers. (FGI CR3 S2)
>
> It's just the school Internet, it's just when you had to use the eBook on the school Internet it just made it more difficult. (FGI CR3 S4)

Installing the software on the students' computers remedied the issue in some cases. However, the program was not compatible with MacOS and most of the students use

Apple MacBook’s running MacOS. Fixing the infrastructure issues was beyond the scope of this study, and given the importance of network access to education, it was not unreasonable to believe the network should support the program.

6.4.1.3.2 Functionality of the e-textbook

New issues arose in this iteration regarding the functionality of the e-textbook. Since this was a continuing cycle of development and refinement, such issues were to be expected and commented on further. The main issue was the user interface (UI), which one student commented on in the Newton’s Laws focus group interview noting that “it is difficult to use, it’s a lot easier to have a physical textbook that you can flick through the pages” (FGI NL3 S3). The UI had been designed to prevent students from moving through the e-textbook (flicking through) without interacting with the information on the pages. However, in the Newton’s Laws iteration, this also prevented students from going back and reviewing previous pages. Modification of the e-textbook in the Chemical Reactions iteration allowed students to move backwards, and they did not raise this issue.

However, a separate issue did occur in the Chemical Reactions iteration with the e-textbook. More hard-scaffolding was included in the e-textbook to assist students with chemical formulae and chemical equation writing by using cognitive tools. Taskin and Bernholt (2014) noted that chemical formulae writing, and chemical equation balancing are two areas that students find difficult. A formulae generator and chemical reaction generator were included to assist students with these tasks. However, some small errors developed in both scaffolds that caused some confusion among students, although they were able to identify the issue and work around it. For example, the chemical reaction generator had one set of reactions missing; however, their observed confidence in writing equations remained high (Table A1.41).

6.4.1.3.3 Note-taking

Students are accustomed to taking notes in class from the teacher, a textbook or another source of information, such as the internet, and this practice is a common aspect of any academic routine (DeZure, Kaplan, & Deerman, 2001). However, the use of computers (laptops) for this task is more controversial. Mueller and Oppenheimer (2014) reported that students using laptops for note-taking performed poorly in recall and application tests. This problem is related to the fact that "if the notes are taken indiscriminately or by mindlessly transcribing content, as is more likely the case on a laptop than when notes are taken longhand, the benefit disappears" (Mueller & Oppenheimer, 2014, p. 8). The students were directed to take specific notes on their laptops that related to the problems they were trying to solve and any research they conducted to prevent indiscriminate note-taking. However, students had an aversion to using their laptops for note-taking, preferring instead to use pen and paper. In the Newton's Laws iteration focus group interview, two students noted that:

> If you had to like write it in your book because writing it you also remember it better if you had to write something in your book I think you'd be better remembering it and it would help or if you had a book that went with the e-book as well. (FGI NL3 S5)
>
> I reckon maybe instead of after like getting information from the e-book and writing it in like the next following page Mr Stewart should maybe print off like a booklet. (FGI NL3 S1)

Another student noted that:

> I thought that there was too much technology used. I think he could have balanced it more with a textbook coz [*sic*] some things weren't needed

> taking notes. There I found it much more like useful writing in books and also having a test at the end, so you know that you are going to have a test at the end you need to know the correct information and the other thing is I thought there was a lot of context there. (FGI NL3 S2)

These responses were unexpected since students had often shown a preference in class for writing notes using their laptops in previous topics. It was possible that this resistance to writing notes in the e-textbook stemmed from the issues raised about the technology infrastructure. That is, students found it difficult to begin using their e-textbooks and were wary of losing the notes they had taken. The issue of note-taking became more problematic in the Chemical Reactions iteration where one student noted that "we didn't really make notes coz [*sic*] just students can't be bothered" (FGI CR3 S4). However, it was interesting that the same student then noted that when it came to write up the practicals, which was the final part of each problem:

> The entire write-up and what we were going to do had to be made up. And that also made us make sure that everything we'd also learned it really confirmed - it was like coz [*sic*] - so, when we have to write up our own practical it means that we really have to know it. (FGI CR3 S4)

In this case, the students needed specific reasons to take notes and researching the topic was, in itself, not sufficient. The students may need more direction on the reasons for taking notes in the form of hard-scaffolding in the e-textbook, especially regarding research notes.

6.4.2 Themes relating to research question two arising from the analysis of the data: features of the e-textbook supported PBL intervention

Cycle three of the iteration identified six themes in relation to features of the e-textbook supported PBL intervention that most influenced student learning. These themes included:

- multimodal
- group work
- enjoyment
- Attitude of student to PBL
- hands-on
- argumentation.

It was possible to group these themes into three broad categories that could be considered together owing to the similar underlying characteristics. Table 6.3 details these categories.

Table 6.3
Themes Contained in Each Category for Research Question Two

Categories	Themes
Facilitation features	Multimodal Hands-on Argumentation Attitude of student to PBL
Interaction features	Group-work
Enjoyment	Enjoyment

6.4.2.1 Facilitation

The inclusion of a feature in the facilitation category meant that it assisted students in learning from the problems presented to them in the iterations. The hands-on nature of the problems together with argumentation were features that students found helped them. The multimodal presentation of the problems to students also facilitated their learning as did the process of PBL itself. A discussion of these two facilitation features occurs below.

6.4.2.1.1 Multimodal

The multimodal design of the e-textbook was continued and improved from the previous cycle and included visual (diagrams and graphs), aural (speaking), reading (text) and kinaesthetic (simulations) aspects. One student noted in the focus group interviews for the Newton's Laws iteration that "it's a better way to describe with an e-book coz [*sic*] you can see what's happening whereas the book just tells you and you have to like accept it even if you don't get it" (FGI NL3 S5). Students also commented on the incorporation of some of the multimodal aspects into videos embedded into the e-textbook:

> better explained because it had videos and things. (FGI NL3 S5)
>
> I think it helped just the understanding from the videos I liked those yeah. (FGI NL3 S4)
>
> I liked the video the most like that's the bit I liked the most having the videos there. (FGI NL3 S2)

The students found the videos and the animations useful in providing information about the problems they were encountering and how to start to work out a solution to those problems. In the Chemical Reactions iteration, which also used videos and animations, the animations could simulate and visualise for students' certain phenomena that may not normally be perceived. Two students mentioned the videos and animations in the focus group interview:

> Watching the videos, I still found myself more engaged … because the eBook's interesting and you learn some basic knowledge. (FGI CR3 S4)

> You can actually like watch animations and get involved, and it's interactive. (FGI CR3 S5)

Therefore, the use of multimedia to present information to students regarding the problem was beneficial.

6.4.2.1.2 Hands-on

The problems presented to the students in both iterations were, to a large extent, practical in nature with an underlying theoretical basis. As such, there was considerable scope for a hands-on approach, which the students liked. In the Chemical Reactions focus group interview, one student noted that "we actually want to do it. When you can see reactions and that sort of stuff it makes you look forward to it" (FGI CR3 S1). Another student noted that "personally I preferred it because it, it is more hands-on" (FGI CR3 S2). A third student provided further explanation noting that "so we had the practicals, but then we also, to understand them, had to read through as well so we got more information and knowledge through that too" (FGI CR3 S5). Therefore, it was not just performing hands-on work for the sake of it, but rather seeing a purpose in the hands-on work they perform as they work through the problem. The positive response to hands-on activities showed in the students' responses to the PBL Evaluation Tool regarding enjoyment of the topic. In the Newton's Laws iteration (Table A1.16), 14% of those students who said they would enjoy the activity indicated it was because it was a hands-on activity, pre-iteration, and this increased to 44%, post-iteration. This preference increased in the Chemical Reactions iteration (Table A1.38) where 40%, pre-iteration, and 100%, post-iteration, of students who responded that the task was enjoyable indicated it was because it was hands-on.

6.4.2.1.3 Argumentation

Argumentation was a constraint in the previous cycle. However, in this cycle, considerable argumentation within the groups was observed in both iterations and across most groups. In the Newton's Laws iteration, the main topics of discussion were how to demonstrate each of Newton's Laws with the materials provided and how to meet the design criteria for the rocket. In the Chemical Reactions iteration, discussions concerned interpreting the results of each set of reactions and how to measure a rate of a reaction while changing only one variable.

6.4.2.1.4 Attitudes of students to PBL

In previous cycles, students had not embraced the process of PBL as fully as was hoped. However, in this cycle, there was a discernible change in the students' attitudes. When asked about problem-solving in the Newton's Laws iteration, one student noted that "I think it helped like thinking more creatively" (FGI NL3 S5). This point was picked up by another student who described the process in more detail:

> Yeah first you have to discuss with your team, and I think they do show that in the online thing. It shows you how to discuss and then assign tasks. That was good I learned a lot from that. (FGI NL3 S1)

Then, when asked if they learned more or less using this method (PBL), another student stated that:

> Through the experiment I actually understood. Usually I read something and I just have to remember what it says, but I actually understood the process better by doing this. (FGI NL3 S2)

There was an appreciation by the students of the value of working through a problem to find a solution and in doing so learn about the topic they were covering.

There was a similar response in the Chemical Reactions focus group interview. When asked what they liked or disliked about the topic, one student noted that:

> It was also easier to grasp the topics when you'd just done an experiment or a practical or a problem on when you've done the work and then you can - it's so much easier to also then also understand the practical once you've also worked out what the problem actually is and how to explain it. (FGI CR3 S4)

Another student explained the advantage of working on a problem further, when asked if they learned more using this (PBL) method by stating that:

> It's like when you're writing down notes you - sometimes you don't really register what you're writing, you just do it. But when you're given a practical you have to actually think about it and figure out what you're doing. (FGI CR3 S5)
>
> At the end of the eBook there was a problem where we also had to go into our textbook, so we had the practicals, but then we also, to understand them, had to read through as well, so we got more information and knowledge through that too. (FGI CR3 S5)

Over both the iterations, there was an appreciation by the students of the value of learning by problem-solving. This appreciation was evident in the Informal Classroom Observations as well as with students actively engaging with the problems in their groups (Table A1.20 and A1.41).

6.4.2.2 Interaction

Interaction is taken to mean any feature that involved students communicating with each other or the e-textbook. The students were involved in interacting and supporting each other in groups. The interaction between students involved discussing the problems and working on solutions, which included interacting with the e-textbook (Table A1.20 and A1.41).

6.4.2.2.1 Group-work

The level of interaction and support within groups in the Newton’s Laws iteration was remarkable both for its sophistication and endurance. The students constantly worked with and supported each other by discussing the problems and working on possible solutions. When asked during the focus group interview for Newton’s Laws, one student noted that “Yeah our team was like had different like everyone had like different like opinions and ability” (FGI NL3 S4). Another student commented that “It kinda [*sic*] pushes you …you’re expected to do something it’s like if you were by yourself, it’s like if you don’t do it it’s your fault but if you’re in a group you kind of have to” (FGI NL3 S2). There was both an appreciation of the value of working in a group by sharing ideas and opinions and a sense of commitment by the members of each group to the other members.

In the Chemical Reactions focus group interview, students again responded positively about group-work. When asked about group-work in PBL, one student noted that “So, it wasn’t just the one person; it wasn’t just you trying to understand the thing, like you had to - and that way the entire group had to have an understanding” (FGI CR3 S4). When asked if they preferred this style of teaching (PBL), the same student said that “it’s also just a whole lot more appealing to be able to walk into science and get to work in a group and not just as a single student in a classroom” (FGI CR3 S4). Thus, this student not only just enjoyed working in a group but saw value in doing so. Further questioning about whether students learned more using PBL confirmed the value they placed on using PBL. The same student stated that “your group actually had to work together to design the practical, so you needed to have an understanding before you could even think about doing the practical” (FGI CR3 S4). Therefore, there was an appreciation of the importance of working together on a problem. While this was only one student, other students in the interview agreed with the idea of requiring an understanding of the purpose of the practical (problem) before carrying it out.

6.4.2.3 Enjoyment

In the Newton's Laws iteration (Table A1.16), 42% of students, pre-iteration, and 64%, post-iteration, found the activity enjoyable in some respect. In the Chemical Reactions iteration (Table A1.38), there was no change in the level of enjoyment pre-iteration and post-iteration with the level remaining at 56%. Informal Classroom Observations also showed the students enjoying the process of PBL in their groups as they were observed to be working together on-task during the cycle.

6.4.3 Themes relating to research question three arising from the analysis of the data: overall impact

The instruments used in this study also gathered data on the overall impact of the e-textbook supported PBL intervention on the students, and analysis of the data identified five key themes:

- content knowledge and its application
- misconceptions
- planning, monitoring & evaluation
- student engagement
- hard-scaffolding.

The Newton's Laws iteration affected students' knowledge with significant improvement post-iteration. Figure A1.3 shows the percentage of correct responses to 10 multiple-choice questions regarding Newton's Laws. A Wilcoxon Signed Rank two-tail test for paired samples performed on this data showed a significant difference between the pre- and post-iteration scores ($\alpha = .05$ and $p = .023$). There was also an appreciable difference between the pre-iteration and post-iteration results when students had to circle up to six words in the list provided to them that they thought related to Newton's Laws and rocket design, but about which they had no actual knowledge (Figure A1.6). Students understood more about most terms post-iteration with only one term recording a decline post-iteration.

Questions relating to describing and applying Newton's Laws (see Table 6.4) indicated substantial improvement post-iteration in most areas, the exception being explaining an application of Newton's Laws, which showed only a slight improvement. This anomaly was owing to students not providing enough detail in their answers. Post-iteration students were able to apply the concepts of Newton's Laws correctly in general as well as specifically to the design of a rocket.

Table 6.4
Percentage of Correct Student Answers to Questions Regarding Newton's Laws Pre-Iteration and Post-Iteration

Topic	Source	Percentage correct	
		Pre-iteration	Post-iteration
Recognition of an application of Newton's Laws	Table A1.1	12.5	44
Explaining an application of Newton's Laws	Table A1.2	70	80
Applying Newton's Laws to rocket design	Table A1.3	60	100
Applying Newton's Laws to rocket efficiency	Table A1.4	22	67

In the Chemical Reactions iteration, there was a similar result with significant improvement in students' content knowledge post-iteration. Figure A1.17 shows the percentage of correct choices for each question. A Wilcoxon Signed Rank two-tail test for paired samples performed on this data showed a significant difference between the pre- and post-iteration scores ($\alpha = .05$, $p = .026$).

When asked questions that related specifically to the topic of reaction rates, the results were positive (Table 6.5). Similarly, when asked about kinetic theory, increasing reaction rate and factors affecting reaction rates, there was a substantial improvement in students' knowledge. However, when asked to explain how a factor increased a reaction rate, there was no great improvement in the student's understanding with students either restating the question or using loose terminology (e.g., increasing just one factor will increase the rate at which the reactants react together). The result would indicate a deficit in student learning in this area. Nevertheless, overall the results indicated an improvement in the students understanding of reaction rates.

Table 6.5
Percentage of Correct Student Answers to Questions Regarding Rates of Reaction Pre-iteration and Post-iteration

Topic	Source	Percentage correct	
		Pre-iteration	Post-iteration
Apply kinetic theory	Table A1.24	30	50
Describe how to increase reaction rate	Table A1.25	60	80
State factors affecting reaction rates	Table A1.26	90	100
Explain how a factor increases reaction rate	Table A1.28	25	44
Measuring reaction rate	Table A1.29	0	34

6.4.3.1 Misconceptions

Table 6.6 shows student misconceptions regarding various concepts involving Newton's Laws as a percentage of total responses. In most of the topics in the Newton's Laws iteration, the percentage of misconceptions present in student responses decreased post-iteration. In the explaining of Newton's Laws, there were no misconceptions pre-iteration or post-iteration.

Table 6.6
Percentage of Responses Containing Misconceptions Regarding Newton's Laws Pre-iteration and Post-iteration

Topic	Source	Percentage of responses containing misconceptions	
		Pre-iteration	Post-iteration
Recognition of an application of Newton's Laws	Table A1.1	25	0
Explaining an application of Newton's Laws	Table A1.2	0	0
Applying Newton's Laws to rocket efficiency	Table A1.4	44	11
Explain how you increased the efficiency of your rocket	Table A1.6	20	12.5

In the Chemical Reactions iteration (see Table 6.7), two of the topics showed a reduction in the percentage of misconceptions post-iteration. However, when asked about how a factor may increase the rate of a chemical reaction, there was a small increase post-iteration. Overall, the level of misconceptions shown by the students was small and for the most part, trended downwards. The iteration seemed to prevent many misconceptions forming and helped remove those misconceptions that did form.

Table 6.7
Percentage of Responses Containing Misconceptions Regarding Chemical Reactions Pre-iteration and Post-iteration

Topic	Source	Percentage of responses containing misconceptions	
		Pre-iteration	Post-iteration
Explaining kinetic theory	Table A1.24	20	10
Describing increasing a chemical reaction	Table A1.25	20	10
Explaining how a factor increases a chemical reaction	Table A1.28	0	11

6.4.3.2 Planning, monitoring and evaluation

Students were asked to rate, using a Likert scale, the importance of five aspects of planning and completing a problem relating to the design and construction of a rocket. A Spearman–Brown split-half reliability test was used to determine if there was any difference between the students rating of the importance of the five aspects pre-iteration and post-iteration in planning and completing the problem. The planning question pre- and post-iteration had an rSB1 = -.240 and the completing question had an rSB1 = .573. These results showed no and little equivalency between the pre- and post-iteration responses, so there was a large difference between the pre- and post-iteration results. Comparing students' responses to the planning and completing questions showed that the pre-iteration results for the planning question and completing question had an rSB1 = .339 and the post-iteration results had an rSB1 = .941. This result would indicate that the students did not see a significant difference between these aspects of planning and completing a problem, post-iteration, but did so, pre-iteration.

When asked the same questions in the Chemical Reactions iteration, the results were different. The planning question pre- and post-iteration had an rSB1 = .786 and the completing question had an rSB1 = .702. These results showed a greater level of equivalency between the pre- and post-iteration responses compared with the Newton's Laws iteration in the completing question. Comparing students' responses to the planning and completing questions showed that the pre-iteration results for the planning question and completing question had an rSB1 = .634 and the post-iteration results had an rSB1 = .800. There was a decrease in the pre-iteration value comparing the planning and completion of the problem, but it was not a significant one and there was an increase post-iteration.

When asked about evaluating their performance on the problems in the Newton's Laws iteration, 70% of students indicated that they would do so by looking at the progress they made, pre-iteration, compared with 90%, post-iteration. The other response was communicating, which 30% of students indicated, pre-iteration, and 10%, post-iteration. When asked to consider how they would evaluate each step 29% of students indicated they would compare with another group member, pre-iteration, which decreased to 12.5%, post-iteration. The number of responses indicating trial and error increased from 0%, pre-iteration, to 37.5%, post-iteration and the number of responses indicating post consideration decreased from 57% to 0%. (Table A1.12 and A1.10).

In the Chemical Reactions iteration, there was a difference in the responses to how students would evaluate their performance with 22% indicating they would use the end result, pre-iteration, and this declined to 0%, post-iteration. The other response was progress made, which 70% of students indicated, pre-iteration, and 100%, post-iteration. When asked to consider how they would evaluate each step, 62.5% of students indicated they would compare with another group member, pre-iteration, which decreased to 11%, post-iteration. The number of responses indicating testing at each step increased from 12.5%, pre-iteration, to 44%, post-iteration, and the number of responses indicating post consideration increased from 25% to 44% (Table A1.34 and A1.33).

When asked how they would search for information in the Newton's Laws iteration, students considered using multiple sources of information with the internet being the most common, pre-iteration, at 67%, and post-iteration, at 55% each. In some cases, the searches were specific in nature and did specify a particular piece of information—for example, “we looked up best rocket designs, based on their weight and aerodynamic design”—that they would search for using resources available. When asked about assessing the information found, the most common student response was to compare it with other members of their group: 71% pre-iteration and 62.5% post-iteration (Table A1.11 and A1.13).

In the Chemical Reactions iteration, students searching for information mainly focused on the use of the internet with 64% indicating they would use the internet, pre-iteration and post-iteration (Table A1.35). One hundred percent of responses post-iteration were general searches rather than specific ones. However, in class, they were observed using more specific search terms (Table A1.41). In assessing information, the most common response, pre-iteration, was comparing it with other group members at 57%. However, this declined to 50%, post-iteration, with increases in relevance and testing accounting for the difference (Table A1.36). The result was not unexpected since the students focused on the outcomes of their investigations into the problem.

6.4.3.3 Student engagement

The PBL Evaluation Tool used two Likert scales to assess student engagement. They ascertained students’ beliefs about their confidence in completing a PBL project without help and the usefulness of the project to them as students. The first Likert scale asked students to rate their confidence level in completing the PBL task. Figure A1.15 shows the results of the first Likert test. Pre- and post-iteration differences tested for using a Wilcoxon Signed Rank two-tail test for paired samples. There was no significant difference between the pre- and post-iteration scores ($\alpha = .05$, $p = .83$). The second Likert scale asked students to rate how useful they thought the task would be to them. Figure A1.12 shows the results of the second

Likert scale. There was no significant difference between the pre- and post-iteration scores ($\alpha = .05$, $p = .681$) using a Wilcoxon Signed Rank two-tail test for paired samples.

The first Likert scale showed only small gains in student confidence post-iteration with increases in confidence at the upper (more confident) end of the scale. There was no quantum lift in student confidence. The second Likert scale showed that there was a wider range of opinions among students about the usefulness of the topic post-iteration. This result was not unexpected given the student's response to the next question (see Table A1.14) where 66% of students, post-iteration, indicated that the end result or supporting the team was the motivation for working on the task. The students saw the iteration as being entire unto itself with no application beyond the iteration. Historically, the students were taught discrete topics in science with a test at the end of each topic. There was no incentive for them to look beyond the completion of each unit of work.

When asked whether the task would be easy or difficult (see Table A1.17), the students' results showed that 11% of students, pre-iteration, and 30%, post-iteration, found it easy. When asked whether the task would be enjoyable (see Table A1.16), 42% of students, pre-iteration, found it enjoyable and 64%, post-iteration, thought that it would be enjoyable. In the Newton's Laws iteration, students found the task to be more enjoyable despite a majority still finding it difficult post-iteration.

The Chemical Reactions iteration also assessed student engagement using two Likert scales. The Likert scales ascertained student's beliefs about their confidence in completing a PBL project without help and the usefulness of the project to them as students. The first Likert scale asked students to rate their confidence level in completing the PBL task. Figure A1.23 shows the results of the first Likert test. A Wilcoxon Signed Rank two-tail test for paired samples was used to test for differences pre- and post-iteration differences. There was no significant difference between the pre- and post-iteration scores ($\alpha = .05$ and $p = .776$). The second Likert scale asked students to rate how useful they thought the task would be to them as students. Figure A1.21 shows the results of the second Likert scale. There was no significant difference between the pre- and post-iteration scores ($\alpha = .05$ and $p = .205$) using a Wilcoxon Signed Rank two-tail test for paired samples.

The first Likert scale showed a greater spread of student confidence responses post-iteration. As in the previous iteration, there was no major lift in student confidence. The second Likert scale showed that students considered the iteration more useful to themselves post-iteration. When asked what their motivation was for working on the task (see Table A1.37), 0% of students, post-iteration, indicated that their grades were a major concern. Only 11% indicated that a good end result was a major motivation and 67% indicated that timing was the motivation for working on the task post-iteration. In this iteration, the main focus of the students was on working to a deadline rather than their grades.

In terms of task difficulty, 11% of students, pre-iteration, and 57%, post-iteration, indicated that they found the tasks easy (Table A1.39). When asked whether the task would be enjoyable (Table A1.38), 56% of students' pre-iteration and post-iteration, found it enjoyable. Thus, they found the task less difficult than expected and a majority found it to be enjoyable.

6.4.3.4 Hard-scaffolding

The students were almost always engaged in some way during both iterations as indicated by the Strobe Protocol Observations (Table A1.23 and A1.42). The hard-scaffolding in the e-textbook guided the students on how to work in groups, and this seemed to have helped groups work cooperatively. In the focus group interview for Newton's Laws, when asked about problem-solving, the students mentioned the group-work scaffolding in the e-textbook:

> First, you have to discuss with your team, and I think they do show that in the online thing. It shows you how to discuss and then assign tasks and stuff. That was good I learned a lot from that. (FGI NL3 S5)
>
> In the introduction where it told you how to, the people sitting on the table, include people, that was really helpful. (FGI NL3 S4)
>
> Yeah, I agree with them and yeah. (FGI NL3 S2)
>
> I think it like helped like thinking more creatively. (FGI NL3 S5)

The hard-scaffolding provided in the e-textbook had made a substantial impact on the students' approach to group-work.

6.5 Summary

The journey has concluded, but a reflection on that journey has revealed much to consider and review. Refinement and modification of the e-textbook occurred over the course of the longitudinal study and a large amount of data produced by the students who took part. These results enable consideration of the implications for the introduction of e-textbook supported PBL in secondary school contexts in the next chapter.