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2018

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

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Chapter Seven: Discussion

7.1 Introduction

The English historian Henry Buckle in commenting on the history of civilisation in England noted:

The great enemy of knowledge is not error, but inertness. All that we want is discussion, and then we are sure to do well, no matter what our blunders may be. One error conflicts with another; each destroys its opponent, and truth is evolved. (Buckle, 1861, p. 518)

The purpose of this discussion is to review the data collected and then commence a dialogue that might provide insight into the use of e-textbooks to facilitate Problem-Based Learning (PBL) in secondary school science. The discussion focuses on answering the three research questions stated in the first chapter. Table 7.1 provides a summary of the key themes that emerged from the three research questions using the results presented in the three preceding chapters.

Table 7.1
A Summary of the Key Themes that Emerged from the Research Questions

Research question	Themes
Research question 1: What constraints (if any) inhibited the implementation of the e-textbook supported PBL intervention?	Learning constraints Pedagogical constraints Technical constraints
Research question 2: What design features of the e-textbook supported PBL intervention most influenced student learning?	Facilitation features Interaction features Enjoyment
Research question 3: What was the overall impact of the e-textbook supported PBL intervention on students?	Knowledge Problem-solving transfer Engagement

7.1.1 The road model used to illustrate the development of the e-textbook to facilitate PBL in secondary school science

This study intended to develop a learning resource in the form of an e-textbook produced by an in-house teacher that would enable science students in a secondary school to effectively use PBL to learn specific scientific concepts and skills. The development of these e-textbooks was evolutionary with refinements occurring to improve the e-textbook to the point where it was an effective tool used in PBL. However, the development of a series of e-textbooks in one school was only a starting point, an embryonic project that has the potential for growth, development and wider application. In viewing this bigger picture, it was valuable to reflect on the design process to highlight areas that future developers could consider in developing the next generation of e-textbooks for PBL.

In reviewing the development of the e-textbooks, it was useful to have a model as the basis for guiding the review process. A road was used as the model since it is metaphorically descriptive of the developmental process of producing e-textbooks for students. A road has a starting and finishing point, and in this case, the starting point was the initial e-textbook and the finishing point was the final e-textbook used by the students (Figure 7.1). The road itself was the pathway followed, with all its obstructions and hazards, to develop the final e-textbook. There was a temporal as well as a spatial aspect of this model, which required a second pathway in the model to reflect changes that occurred (Figure 7.16).

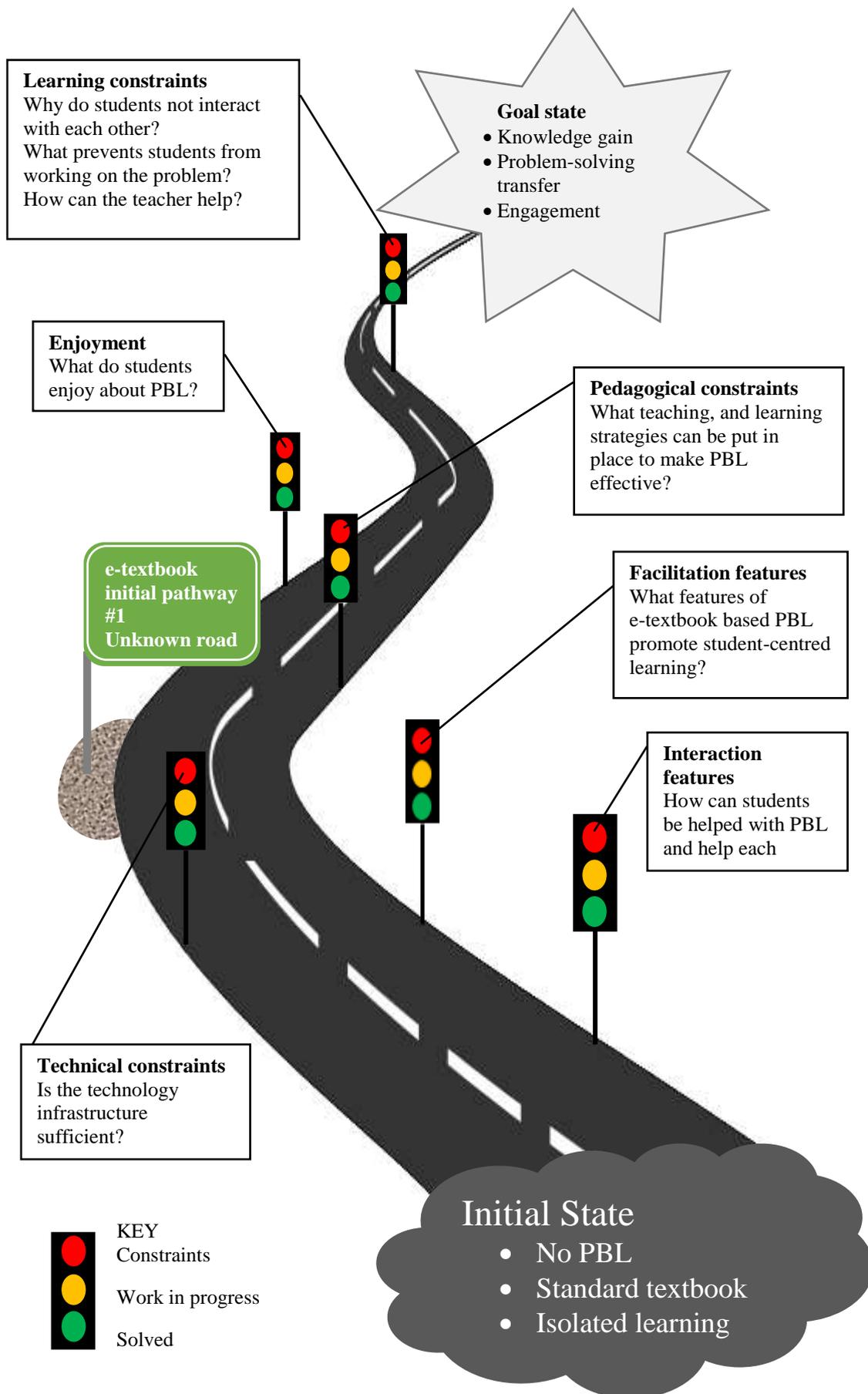


Figure 7.1. The initial road model describing the development of the PBL e-textbook.

Roads are never perfectly straight, free of control points or obstacles and are undergoing construction—so it was in the model used in this study. While the attainment of the goal state was significant, it was the journey along this road with all its control points and construction sites that was the main consideration since this journey provided insights into the design process of the e-textbook. This road model is considered again at the end of this chapter and a determination made regarding the attenuation, or otherwise, of the obstacles and control points in light of this study.

7.2 Research Question One: What Constraints (if any) Inhibited the Implementation of the E-textbook Supported PBL Intervention?

This first research question concerned the constraints that impeded the putting into practice of the e-textbooks to support a PBL environment in a secondary school science classroom. Therefore, it was necessary to consider the various factors that hindered the use of e-textbooks to promote PBL. These factors were distilled from the analysis of the data and consisted of learning, pedagogical and technical constraints. The subsequent remediation of these factors provided some insight into the implementation of PBL into secondary school science classrooms.

7.2.1 Learning constraints to the use of e-textbooks to promote PBL

Learning constraints covered several different categories, including group dysfunction, distraction, copying, the function of the e-textbooks, prior knowledge, the nature of the topic and student expectations of the teacher. Broadly speaking, these categories could be coalesced into five main ideas regarding student interaction: interaction with each other, the technology, the problem, teacher and the institution. The number of constraints decreased as the study progressed.

7.2.1.1 Student interaction with each other that was incompatible with PBL

The literature has documented the importance of interaction between students (Aziz & Hossain, 2010; Chapman, Meuter, Toy, & Wright, 2010; Johnson & Johnson, 1982; Okebukola, 1985; Sharan, 1980; Webb, 1982). Sharan (1980) described the cooperative learning environment as one consisting of small groups that engender cooperative interaction to study a specific area under consideration. He further noted that these groups “become the social unit in which learning is pursued, instead of the class as a whole or the individual pupil” (Sharan, 1980, p. 242). The individual student in such a situation is less able to ‘hide in the crowd’ and so is more likely to be called upon to contribute to the group. However, the requirement of individuals to contribute to the group led to group dysfunction where students displayed a variety of behaviours incompatible with successful PBL group-work. Chin and Chia (2004) identified some of these behaviours, including how to proceed as a group, what information was relevant and allocation of tasks to group members. As PBL is a group-based learning tool, effective group dynamics are important (Savin-Baden & Major, 2004) and dysfunctional groups can hinder achievement of its goals (Dolmans et al., 2005). Other observed behaviours were described by Wood (2004, p. 3) as the flight, fight and pairing responses. In these situations, students would withhold information from other group members (fight), not take part in group discussions (flight) or work with only part of the group (pairing).

By Year 10, and with two years of secondary school experience that would have involved some group-work, the observed students’ inability to work with a group from the start was surprising. Therefore, it was necessary to explore this observation further. The type of group-work required of the students in the first cycle

was different from the standard work in a group format that students participate in at school. In working in a science class group format, students typically are given a task (not a problem) and told what to do and how to do it. The only requirement then is for the students to adopt groups and carry out the task. Activities such as this require minimum interaction between the students so that, effectively, they work on small individual tasks. In the case of PBL, the situation is markedly different. The students needed to collaborate to solve a problem that does not have an immediate answer and are required to do more than just completing a set task (Scott, 2014). Students found it difficult to adjust to this paradigm of group-work, which was different from their established perceptions of working in a group. A comment from one student illustrated the issue:

When you're in a group you sort of get a bit off put sometimes. You get a bit distracted especially when I don't know because we all like had to work together sort of thing, but other people in my group don't really work. (FGI NL1 S3)

Students were not able to work collaboratively towards a common goal.

The level of collaboration improved in the second iteration owing to two factors. First, the students became used to working in PBL groups, and second, and almost counter-intuitively, they responded better to random group placement. In the focus group interview at the conclusion of the first Chemical Reactions iteration, a student commented that “So you [indicating another group member] could sort of focus on something and I could focus on something then we could just collaborate and it would be a lot more efficient way of learning” (FGI CR1 S2). All of the other students agreed with the comment made by this student. The improvement because of familiarity with working in PBL groups was not unexpected, since students had

some experience in working as a group, albeit with different ground rules. The students had expressed that they had experienced a paradigm shift regarding what group-work involved, and so, they could function more effectively owing to their previous exposure to PBL group-work. The types of interactions that occurred in the groups explained the second observation. In friendship groups, there was competition between non-productive social interaction and productive social interaction. The non-productive social interactions would involve collaborations that did not relate to the problem, but rather to off-task socialising, including gaming (e.g., playing MinecraftTM), noted during observations of the class. The latter refers to on-task interaction related to the problem. In random groups, there was less opportunity for students to engage in non-productive social interaction. Typically, this was due to students trying to find common ground for communication. Friendship was not an option, and therefore, they had two choices: interact with each other about the problem or not at all. While it was possible for students to disengage, this did not occur since a new dynamic evolved in the group. As one student noted in the same focus group interview, “we aren’t really close friends outside but the group-work may have brought us a bit more closer” and “I was going to make sure I was participating in my group and I wasn’t going to slack out or anything like that like I wanted to help my group and have equal jobs” (FGI CR1 S4). This evolution of a different interaction within the group may not have arisen spontaneously, and it was necessary to develop productive group interaction.

There was a change in the e-textbook design to facilitate group-work to achieve better group interaction. Figure A2.2 shows the modification to the PBL introduction for students. The modification aimed to improve student interaction and PBL skills rather than relying on the students acquiring the skills. However, there

was no noted improvement in the student's initial interaction, and so, the decision was made to modify the e-textbook further. Students received feedback after they had completed the assessment regarding their PBL skills (Figure A2.3) about what they did incorrectly and how to improve in each aspect of the PBL skills (Figure A2.4). The feedback made very little difference to student interactions within groups, and there were numerous occasions when the groups were dysfunctional. If the group perceived the problem to be too difficult, it no longer functioned to support its members and became dysfunctional. Individuals could not cope with their specific tasks, and so, these reverted to the group, which then failed to work cooperatively. This was exemplified in the focus group interview for the Newton's Laws (cycle two) by a student that commented "I think coz [*sic*] some people got confused by it and didn't understand they just they didn't contribute to it very much, so some people just decided to forget about it and let other people do the work in that group" (FGI NL2 S4). The comment highlighted the issue with PBL in students who expect all the information at the start of the problem. In the same focus group interview, another student commented that "but other people don't get it ... like understand what we had to do coz [*sic*] it wasn't really straight forward" and "but we should have had a little bit more information on what we were supposed to be doing" (FGI NL2 S6), which illustrated a lack of understanding about the principles of PBL.

Students' expectations expressed in the focus group interviews necessitated further changes to the presentation of the information to them about PBL, including how to work in a group. The presentation information on group-work was in two parts (Figure A2.5) with part one serving as a general introduction and part two dealing with specifics, including group-work. It was decided to include an assessment of how the students understood PBL (Figure A2.6) and to provide

specific feedback about how they could improve in areas where they had not fully understood the concepts covered (Figure A2.7). The feedback strategy was implemented not because of how the students were performing as a group, but rather from a concern about their understanding of the PBL process, stemming from student comments about not being given sufficient information at the start. The presentation regarding PBL now also required the students to work through the sections on group-work rather than allowing them to skip through the section. That the students had to engage with the presentation caused them to stop and think about the information in the e-textbook. There was mostly positive on-task interaction between group members. Students worked cooperatively in groups in both iterations as indicated in the Strobe observations (Table A1.23 and A1.42) and informal classroom observations (Table A1.20 and A1.41).

In classes where students use laptops as a tool for learning, there is the possibility of multitasking occurring where they engage in activities not related to their studies (Fried, 2008; Junco, 2012; Sana, Weston, & Cepeda, 2013). One such activity is playing games (Bate et al., 2014), which can distract students from the educational purpose of using their laptops when the game is not part of the educational experience, as was the case in this study. In the first two cycles of this study, game playing was an issue mentioned in the focus group interviews. The ease with which students could switch between the required task and playing a game was a factor contributing to this concern. Students created the impression of working on the task they were supposed to while spending some of their time off-task.

The time spent in game playing declined over the course of the study, and it was important to determine why there was a difference between the level of gaming

from the start of the study to its conclusion. The nature of the learning experience regarding its structuredness can have an impact on student use of technology in environments where such technology is freely available (Kay & Lauricella, 2011; Mohammadi-Aragh & Williams, 2013). This structuredness relates to how technology integration into the students' learning experience occurs. In an unstructured learning experience, the technology is present, but not incorporated in any way whereas in a structured learning experience, the technology has specific integral purposeful uses (Mohammadi-Aragh & Williams, 2013). However, these are two extremes, and perhaps greater insight lies somewhere in the middle. Indeed Mohammadi-Aragh and Williams (2013) noted the existence of situations where no clear distinction between structured and unstructured occurred. A similar situation existed in this study, albeit for a different reason, which is the very nature of the e-textbook. The problems presented to the students were all similar. However, the presentation of the problems was different (Figure A2.8, A2.9 and A2.10).

Initially, there was very little structure regarding how to work through the problems presented in the e-textbook. Information provided to the students was largely text based with questions used to focus their attention on the salient facts they needed to work through the problem. There was no attempt to inculcate in the students an ethos of collaborative group-work and minimal experimentation for them to work on as a group. Feedback to the students was also minimal and restricted to corrections to incorrect responses to multiple-choice questions (Figure A2.8). Thus, the structure of the learning experience was loose; the students had their laptop and the e-textbook and were expected to use them effectively. Support regarding hard-scaffolding was minimal, and so, there was a heavy reliance on soft-scaffolding. In relying heavily on soft-scaffolding, distraction was more likely to occur because

the facilitator must spend more time with each group with the result that other groups could go off task.

As the study progressed, the design of the e-textbook was modified to attempt and provide a more interactive and scaffolded learning environment for the students. The modifications included animation to illustrate how PBL worked, including working in groups, Newton's Laws and rocket design. When students' results indicated an insufficient level of understanding, the level of feedback and remediation provided to students was increased. A review of each problem was conducted for the students, and they received assistance with producing their report. Thus, there was more hard-scaffolding in addition to the soft-scaffolding (Figure A2.9). Despite these changes, there was still distraction especially in the form of socialising and game playing.

Further modifications to the e-textbook largely concerned the functionality of the e-textbook and are discussed later in this chapter. However, improvements were made to the presentation of the experiments by moving them from a whiteboard to a table in the lab scene and information presented to the students on each page was reduced (Figure A2.10). Students had more structure through the provision of soft-scaffolding, and the level of distraction decreased substantially. In the focus group interviews for cycle three for Chemical Reactions and Newton's Laws, no mention of gaming was made by students, whereas in previous interviews, they openly commented about gaming. There was less off-task behaviour noted in the classroom observations. The use of soft-scaffolding to respond to student's specific needs on an as-required basis worked to reduce the problem of distraction.

Ryu and Sandoval (2015, p. 337) noted that students working in groups must deal with a variety of issues, including “differences in experience, values, and goals during collaboration” in addition to working on the problem they are attempting to solve. Gillies and Haynes (2011, p. 351) noted that “it is only when students have been taught how to communicate that the benefits attributed to this approach to learning are realised.” The intervention should include “not only the skills of learning to communicate effectively through listening, explaining, and sharing ideas but also those skills needed to plan and organise their work” (Gillies & Haynes, 2011, p. 351). This study found that some of this upskilling could occur in the e-textbook to reduce the demands placed on the teacher to provide basic group-working skills including communicating. Such upskilling does not replace the teacher, who must be prepared to intervene on an as-needed basis in response to specific issues that are difficult to plan for in advance.

Copying was a major issue in the initial stages of the study. Copying can have many causes that include:

- Academic self-efficacy;
- Academic interest;
- Academic level;
- Task importance;
- Task clarity and relevance; and,
- Peer pressure.

(Cheung, Wu, & Huang, 2016, pp. 248–249).

Only a few of these factors were at play during the course of the study. A student’s belief in their abilities will affect their attitude towards cheating with those having a higher self-efficacy less likely to engage in such behaviours as plagiarism (Marsden, Carroll, & Neill, 2005). Academic interest relates to students’ goals regarding mastery (high interest) or performance (low interest) (Cheung et al., 2016) with those

in the latter group more likely to cheat (Anderman & Midgley, 2004). Academic performance (level) is a factor in determining the level of cheating by students, but cheating by low-ability students can be mitigated by strongly identifying with the school they attend (Finn & Frone, 2004). Ashworth, Bannister, and Thorne (1997) noted that the importance students attribute to a task was a determiner of the level of cheating with higher levels occurring when they perceived the task to be less important. The significance and level of ambiguity are also determiners of the likelihood of cheating with less cheating occurring when tasks are unambiguous and considered valuable by the student (Anderman, 2007). Finally, the impact of peers can affect the level of cheating with such behaviour correlating with the attitude of a student's peers to cheating (McCabe & Trevino, 1997).

The self-efficacy of the students in this study was not an issue with students confident in their ability to complete the task and an increase in this belief post-intervention (Figure A1.13, A1.14 and A1.15). Further, the majority of students, with the exception of those of Newton's Laws, cycle two, felt that the task they were working on was useful to at least some extent, and so, disinterest, relevance and lack of importance are not relevant. Initially, the students were part of a lower achieving group (as identified by their school test and exam scores), and so, this is a possible contributing factor to the copying observed. The clarity of the task was an area that proved to be a justifiable cause for the copying that students engaged in during the intervention. The tasks were designed to be vague since PBL requires problems that have no immediate solution, and the students found it difficult to work with the problem effectively. Peer pressure was another factor that influenced students with one student commenting in focus group interviews that they copied work from each other within the group because others were also copying.

In the latter stages of the study, copying was no longer an issue. Possible explanations for this observation include the following. First, the students were now a heterogeneous mix of ability levels with each group consisting of members at various levels of academic ability. Second, there was more soft-scaffolding to ameliorate the need for students to copy each other's work, which Anderman (2007) noted as a factor in preventing cheating.

Productive work does not automatically result from students working in groups despite many students preferring to do so. It was more productive to construct groups that were not friendship-based but heterogeneous. The data collected over the course of this study support the idea that groups composed of students of differing abilities randomly assigned to their group and provided with appropriate scaffolding were the most successful. Williams (2011) noted that friendship grouping was more productive; however, in the present study, such grouping provided opportunities for non-productive interaction of a more social nature rather than working collectively to develop a solution to the problem. Grouping students of similar ability did not produce the level of sophistication in their interactions that was required. When the students were in mixed ability groups, they could interact and support each other. They would listen and respond to each other, allocate tasks (sometimes as a group) and research information when required. The actual grouping of students was not a function of the e-textbook but one that a facilitator in a PBL environment using e-textbooks should be aware of when setting up the groups.

7.2.1.2 Student unrealised expectations of the e-textbook technology

The issue of the extent to which students interact with the e-textbook here is not one of a technical nature, such as accessing the network, but rather one of an expectation of what a textbook should do for the student. The e-textbook did not

provide all the necessary information for the students which was a clear difference between it (Figure A2.9) and the traditional textbook. There was no specific information about the problem, but only about how the students may go about working through the problem in their group. The fact that the students had used the traditional textbook in a previous topic exacerbated this issue. The disconnect between what the students expected from a textbook and what the e-textbook provided caused them to regard the e-textbook unfavourably, since they considered it to be lacking in essential information. Student comments in the focus group interview for the cycle one Chemical Reactions topic exemplified this disconnect:

I don't feel it contained enough information to guide me in what we were doing, a lot if it I had to ask or research it myself, so I felt it did not contain enough information. (FGI CR1 S3)

If you're reading a normal textbook after each thing you have learnt there is a list of questions and writing those out you're actually taking it in and you're able to identify things that might be in the test so that definitely helps. (FGI CR1 S3)

Normal textbooks have a broader range which is quite useful in understanding the overall topic. (FGI CR1 S1)

This issue continued despite the purpose of the e-textbook being explained to the students at the start of each iteration so that their expectations of what the e-textbook would and would not provide were delineated. There appeared to be an ingrained belief in students that a textbook should provide 'the answers' and given that throughout most of their schooling this is the case, it is a difficult belief to change.

Songer and Linn (1991, p. 772) noted that students who approach science textbooks have fixed beliefs about the nature of science "often believ[ing] that all scientific principles in textbooks will always be true, and they view science as best learned by memorizing facts rather than attempting to understand complicated

material.” Therefore, denying these students facts to be learned and requiring them instead to research information and apply it to a problem created confusion. The students came to the textbook expecting it to provide all the information they needed to remember. This issue was exacerbated by “textbooks and exercises in them often emphasiz[ing] procedural skill” (Kollöffel & Jong, 2013, p. 377) that Rittle-Johnson, Siegler, and Alibali (2001, p. 346) describe as “the ability to execute action sequences to solve problems, and the reproduction of facts and definitions.” Thus, students expected that the textbook would tell them how to solve the problem with a set of procedures rather than requiring them to develop their own procedures to solve a problem. However, Mayer, Bove, Bryman, Mars, and Tapangco (1996) reported that students provided with a detailed explanation of a particular phenomenon are still unable to transfer the information to a related problem. So, simply providing the students with all of the information needed is not a solution to help them engage effectively in PBL. Mayer (2003) found that using multimodal presentations supports students’ learning and application of various concepts using different, but complementary, media. This media may include text, simulations, animations and audio. Sobhanian (2016) cited numerous examples of improvement in student learning when using multimedia programs, especially in science and mathematics.

In this study, the facilitation of the student’s interaction with the e-textbook occurred in several different ways. The VARK model, discussed in the Literature Review, was used to present ideas to students to accommodate the different learning styles they used. While the VARK model has been criticised, especially regarding its treatment of learning styles, it is still a common model, and students tend to identify with one or more of the learning styles (Ganesh & Ratnakar, 2014). The e-textbook assessed student understanding of various concepts and provided feedback and

targeted support when needed. The e-textbook had note-taking facilities and students also had access to glossaries in later cycles. The students had specific support tools that they could use to, for example, write chemical formulae and balance chemical equations. Improvement to such tools occurred in each successive cycle during this study. In this way, the e-textbook was superior to a standard textbook in its ability to support students in a PBL environment by providing a greater range of presentation media and targeted scaffolding when required. The issue of student expectations becomes a hurdle to overcome rather than an obstruction per se, and they require continual reinforcement regarding the purpose of PBL.

7.2.1.3 Difficulty with students' interaction with the problem

To interact with the problems presented to them, students required a certain amount of assumed prior knowledge. A lack of such knowledge would be detrimental to the students in their attempt to work with the problem. The amount of required prior knowledge varied depending on the topic, with no prior knowledge needed to work on Newton's Laws because it was a topic discrete of previous physics topics. However, the Chemical Reactions topic did require some previous knowledge that many of the students lacked and which hindered progress through the problem. Ideally, the students would recognise this deficiency in their chemistry knowledge and work to resolve it. However, initially, the students were not able to do so since they found the problem overwhelming and it was necessary to address these knowledge deficits by having a mix of abilities in both the class and in their groups. As such, each group had students with sufficient background in chemistry to work with the topic as a group and issues with prior knowledge did not develop. Three quotes from the Chemical Reactions focus group interviews illustrate the change in the way the students worked with the problems:

Once we got into it, we were very good like we would share our opinions and ask each other questions, so that definitely helped. (FGI CR1 S3)

I think we all worked well in the team as well with the experiments we all knew what our strengths and weaknesses were and we played to those. (FGI CR1 S1)

If someone didn't have a complete understanding you could then help them, like that group with just that person rather than the teacher having to go around to every person and having to explain it. (FGI CR3 S4)

A second issue concerned the problem presented to the students. Initially, a major focus of the Newton's Laws topic was the design and building of a model rocket taking into account Newton's three laws of motion. These laws were covered briefly in the e-textbook, and a large part of the e-textbook was devoted to the designing of a model rocket. The unfortunate consequence was the students' focus on the rocket as the only problem in the e-textbook. As one student in the Newton's Laws focus group commented "Well I definitely liked building the rockets, but I think filling out the workbook we might have got off the topic a bit, and it was sort of wasn't really done in a proper way where we all really worked together" (FGI NL1 S4). The 'filling out of the workbook' referred to the research the students were required to do before starting the rocket design, something which they did not properly complete. Increasing the focus on each of Newton's Laws before working on the rocket reduced the emphasis on building the rocket by having students work on separate problems related to Newton's Laws: This was commented on by students in the focus group interviews for Newton's Laws where they refer to the problems as experiments or pracs.

Like through the experiment I actually understood like usually I read something and I just have to like remember what it says but I actually understood the process better by doing this. (FGI NL3 S2)

I think I learnt more especially like with the pracs and everything like helping to like fill in everything and actually like put it into real life and stuff. (FGI NL3 S4)

Students needed to process the problem they were working on and needed the skills to be able to do so effectively. They needed to analyse the problem and plan their approach as well as research information and use appropriate equipment. They should possess, and be able to apply, prior knowledge, test ideas and be able to analyse their results, which is what Bogard et al. (2013, p. 467) termed “giv[ing] the problem form.” The problem itself needed to be sufficiently structured so that students could analyse it effectively, but not so structured that a solution was immediately obvious. Presenting problems in small easily manageable sections that related in some way was essential. The problem should not become all-consuming since it was the process of solving the problem through the development of problem-solving skills that was the focus. One student commented on the development of these problem-solving skills in the focus group interview on Newton’s Laws: “Yeah I feel that, I feel that I’m better at like problem-solving experiments which are the main like idea of the online booklet” (FGI NL3 S1).

Students need also to be able to transfer their problem-solving skills from one problem to another. If students cannot apply the problem-solving skills acquired in one problem to a future one, then those skills are too localised and problem dependent and, while near transfer may occur, far transfer may not (Jonassen, 2000). The issue of transfer remains problematic, and it was possible that improved scaffolding may have a role to play in improving transfer, but this remains uncertain. There was no evidence from classroom observations or focus group interviews of students being able to transfer problem-solving skills.

7.2.1.4 Unrealised student expectations of the teacher

The role of the facilitator in PBL is of critical importance (Ertmer & Simons, 2006; Hmelo-Silver, 2004); however, this role was a difficult one to implement given the students' expectations, familiarity with PBL and background knowledge. Ates and Eryilmaz (2015) found that students lacking sufficient background in topics preferred tutors who were specific in the support they provided rather than those who merely facilitated the group. They also noted that "Novice students attending PBL curriculum are unfamiliar with the PBL process ... need guidance and rely heavily on their content expert tutor" (Ates & Eryilmaz, 2015, p. 827). Scaffolding is the obvious solution to this issue, but to simply imply that this will solve the problem is an oversimplification. Chin and Chia (2004) listed numerous issues, including how to proceed as a group and allocation of tasks to group members, that were encountered during a Year 9 Biology class. Similar issues appeared during this study and varied in nature, which required input and guidance from the facilitator. The fact that the students had no previous experience with PBL combined with their limited background knowledge made it difficult for the facilitator to provide all the necessary scaffolding. The hope was that the e-textbook would alleviate this problem by hard-scaffolding some of the processes involved in PBL. Initially, the amount and level of hard-scaffolding provided was inadequate. Subsequent revisions of the e-textbook improved the situation and reduced the amount of scaffolding expected of the facilitator. Therefore, the facilitator could assume the more customary role of providing guidance and the students were more accepting of this role.

Throughout the three cycles of this study, the role of the teacher as a facilitator changed continuously and this made transferring soft-scaffolds from the

classroom into hard-scaffolds in the e-textbook problematic. As the study progressed, it was possible to identify some abilities that were transferable, including group-work, researching and engagement. However, some issues remained difficult to transfer because either the issues were transient (such issues included specific personality differences and prolonged absence of students) or they did not readily lend themselves to incorporation in the e-textbook. While an e-textbook can help alleviate the demands placed on a facilitator by continual updating of the hard-scaffolding, it cannot replace the facilitator completely.

7.2.1.5 The institution's educational philosophy's impact on students

PBL will be most effective when it is incorporated into the educational philosophy of the whole school rather than in isolation (Barrows, 1996; Kolmos, 2002) since the skills learned are reinforced and transferred (Gillies, 2008). Furthermore, there is less stress placed on students when they do not need “to move in and out of different learning approaches, passive versus active, dependent versus independent” (Barrows, 1996). The teaching philosophy of the school began to slowly change from cycle one with the appointment of a new principal who supported active learning over passive learning. As a result, students gradually became more accepting of the PBL approach as it became more widely adopted. As a result, it both reduced the students' concerns regarding the PBL approach not being an effective teaching method and acted to reinforce the skills they needed to take part in PBL successfully.

7.2.2 Pedagogical constraints to the use of e-textbooks to promote PBL

Some pedagogical constraints prevented students from fully benefiting from the PBL environment. These included inadequate scaffolding, lack of argumentation

and a lack of understanding around PBL. Each of these constraints prevented some students from gaining the full benefit of PBL as a tool for their learning. As such, it is essential to discuss each separately to identify the characteristics of each.

7.2.2.1 Inadequate scaffolding

The importance of scaffolding in PBL has been well documented (Bulu & Pedersen, 2010; Greening, 1998; Hmelo-Silver et al., 2007; Kim & Hannafin, 2011; Saye & Brush, 2002; Simons & Klein, 2007). During this study, students received both domain-general prompts relating to problem-solving skills and domain-specific prompts that relate to specific topics they studied. Initially, the scaffolding was at a minimal level, which was ineffectual, both in the domain-general and specific categories. Figure A2.1 illustrates this minimalist approach to domain-general scaffolding, and Figure A2.8 illustrates the same approach in domain-specific scaffolding. Revision of the scaffolding to make it more extensive occurred in both domains (Figure A2.7 and A2.9). As shown in the evidence, the revision did not improve the situation since students were still not functioning well in groups and not interacting effectively with the problem. Therefore, there was a separation of domain-general information into two parts (Figure A2.5), one was an introduction, and the other dealt with specifics, including group-work. There was also an inclusion of an assessment of how the students understood PBL (Figure A2.6) and specific feedback about how they could improve in areas where they did not fully understand the concepts covered (Figure A2.7). This type of scaffolding improved the students' work in groups. Comments in the focus group interviews for Newton's Laws illustrated this point:

I liked the video like it was like each slide not each slide but some slides had the video like explaining like how it works and so I thought that was really useful. (FGI NL3 S2)

Another student added specifics to this point by detailing what was provided to them in the video about group-work.

First you have to discuss with your team and 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).

The domain-specific scaffolding was also improved. These improvements involved developing better presentations for each of the problems and formulating questions for the students to reflect on after they had completed the experimental phase of the problem (Figure A2.10). Further domain-specific scaffolding was provided to support students in areas of weakness traditionally experienced by chemistry students, formula writing and equation balancing (Figure 7.2), by providing cognitive tools for both areas. These enhancements greatly improved the students content knowledge and group-work. A Wilcoxon Signed Rank two-tail test for paired samples performed on the tests of students showed improvement in knowledge. It showed a significant difference between the pre- and post-iteration scores ($\alpha = .05$ and $p = .023$) and scores ($\alpha = .05$, $p = .026$) for Newton's Laws and Chemical Reactions. Student comments from the focus group interviews show effective group dynamics:

We weren't really friends, but now we're pretty good friends, and it was like, it was good getting their opinions because some of each other are smarter in different ways and like I think they really helped us doing the practicals and figure out what we were supposed to be doing. (FGI NL3 S5)

Because you can all work together, and it made it easier to get results because instead of having everyone have to write down the results you could go in case you missed anything. (FGI CR3 S5)

The group-work itself it made you want to do science because usually when we do the pracs I'm usually the one that does it by myself. (FGI CR3 S2)

Students were using the hard-scaffolding extensively for formula and equation writing as observed in the classroom observations. Support in the e-textbook was in the form of hard-scaffolding that was hardwired into the e-textbook before it was available to the students. Therefore, it was unchangeable during each iteration. In this study, providing minimal hard-scaffolding was found to be ineffective in supporting PBL and created a situation that required the use of large amounts of soft-scaffolding by the facilitator. This provision of soft-scaffolding placed too much pressure on the teachers because they worked with several groups, all of which required support at one time.

However, to attempt and provide all necessary scaffolding hardwired within the e-textbook was not a viable alternative since some scaffolding was group and problem dependent and could not be hardwired. Thus, there was a balance between the two types of scaffolding and this balance was not static (Figure 7.3). A basis for deciding about the types of scaffolding, including student familiarity with PBL and the dynamics of the groups engaged in PBL, was required. Consideration also needed to be given to the type of hard-scaffolding provided to the students. Students had received scaffolding in two main areas: PBL (such as working in groups and researching information) and specific science concepts. It was crucial that these types of scaffolding not only presented ideas and skills to the students but also assessed each student's understanding of these concepts and skills. Furthermore, where the assessment found that there were deficiencies in the student's understanding, feedback was provided to the student.

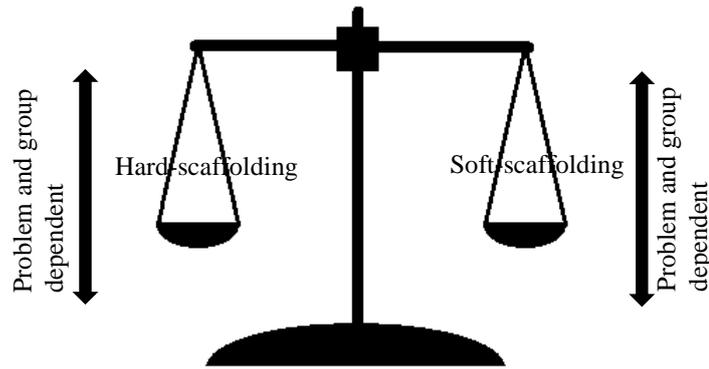


Figure 7.3. Scaffolding in e-textbooks is a balance between hard and soft and is variable between groups and problems.

7.2.2.2 Lack of argumentation

Argumentation is important in the PBL process (Belland, 2010; Belland et al., 2011; Cho & Jonassen, 2002). However, what is less clear is how to achieve argumentation. Gillies and Haynes (2011) believe it is the role of the teacher to provide soft-scaffolding to students that assist them in developing argumentation. However, there is a competing contention that hard-scaffolding should be used (Belland, 2010; Belland et al., 2011; Cho & Jonassen, 2002).

There is an issue with hard-scaffolding in that it is not easily able to respond to individual situations that are inherent in group-work. Ryu and Sandoval (2015, p. 350) noted that “more attention should be paid to the social influences on student argumentation and collaboration.” The dynamics of each group will affect the level of cooperation and argumentation that occurs. For this reason, soft-scaffolding was used in this study to respond to a student’s or group’s needs on an as-required basis and hard-scaffolding for other supports, such as initial group working techniques and content-specific cognitive tools.

In the nascent stages of this study, argumentation was considered a ‘bridge too far’ for students who had no prior exposure to PBL and with e-textbooks that focused on collaboration without the addition of argumentation. As the study progressed, argumentation received due attention with different results in each case. Where there was very little argumentation, there was poor group dynamics and where there were effective group dynamics, high levels of argumentation were observed, which supported the earlier decision to rely on soft-scaffolding. Ryu and Sandoval (2015) noted that the type of exchanges occurring in groups between their participants determined the level of argumentation. This study supports the finding that argumentation can be encouraged using soft-scaffolding.

This study has shown that argumentation is a factor in the success of PBL. Through this style of discourse, students will be able to construct their understanding of the problem’s solution, and more importantly, have that understanding challenged and tested, so that identification of misconceptions can take place and can be corrected. Argumentation is not a spontaneous occurrence but rather, one that develops and matures within a group. Therefore, argumentation is a group-dependent feature, which, despite having some generalisable characteristics, will be the product of interaction within the group. Effective group dynamics was a prerequisite for argumentation, but insufficient by itself, and was very difficult to quantify in the present study. Classroom observation of students in the last cycle that reflected on the interactions the teacher had with the groups was indicative of argumentation. Students had particular opinions or ideas that they brought to the group and which they had to defend with research against other students’ informed questioning. Such interaction was not observed in earlier cycles when student achievement was much lower as indicated by pre- and post-iteration testing. Therefore, the logical argument

is that given effective group dynamics, the development of argumentation must receive support in some way. This support can be in the form of hard or soft-scaffolding, and the relative amounts of each and its form is highly variable; as Belland et al. (2011, p. 669) noted, this should be “developed based on students’ anticipated needs during a PBL unit.”

7.2.2.3 Students lack understanding of the purpose of PBL

The change from a didactic teaching approach to PBL is challenging and disconcerting for students who have only experienced traditional teaching methodologies (Strobel & Van Barneveld, 2015). Alessio (2004, p. 32) noted that students in PBL courses had “partiality towards didactic or directed learning, perceptions of reduced learning efficiency, and feelings of uncertainty.” These feelings of uncertainty and discomfort were also reported by Ates and Eryilmaz (2015). Throughout the study, there was confusion among the students as to the purpose of PBL. In the first cycle, this confusion manifested itself in the form of student’s having expectations of the teacher that were contraindicated by the PBL process as seen in the focus group interview responses where students had certain, unmet, expectations of the teacher.

Also like, how to put this in or how to make to this in. Even though the program that we had to work on to design our own bit and figure out how high it could even though it was help, but it wasn’t like Mr Stewart’s help. (FGI NL1 S2)

In the latter stages, the confusion became more pronounced with students questioning the actual process and preferring a return to a more didactic approach as opined by one student in the focus group interviews.

If we have an open class that can ask questions of the teacher and talk to each other throughout the entire class and just be given the experiments and

do normally as if it was part of the book. Not having and I think it would be a lot more efficient if we just continued doing it the normal way. (FGI NL3 S3)

Therefore, they did not feel comfortable with the challenges it presented to them despite knowing what the process of PBL was about in the iteration.

When presented with PBL environments, especially for the first time, students find the change to a *learning* emphasis from a *teaching* emphasis challenging and confronting (Henry, Tawfik, Jonassen, Winholtz, & Khanna, 2012). They are no longer in their comfort zone as a passive recipient of someone else's knowledge, but an active constructor of their own knowledge. It is demanding and challenging to develop in these students an understanding of how PBL can help them learn new concepts more effectively and develop new skills that can they can apply to problems encountered both at school and beyond the classroom. Crucial to this issue is the group and how it responds to the challenge. If the group is resilient and confident, then it will be able to work through the problem regardless. If the group is dysfunctional, then it will require their interaction to be supported before any progress on understanding PBL can be made (Albanese & Mitchell, 1993; Hung, 2011). Classroom observations in the first cycle indicated that students were out of their comfort zone. The Strobe Protocol in the first cycle showed only half the groups involved in on-task behaviour in the first three observations. When asked about how difficult the activity would be in the first cycle (Newton's Laws), 38.9% of students (pre-iteration), who said it would be difficult, stated that it was because it was unfamiliar, and this rose to 54.5%, post-iteration. In the third cycle, task difficulty decreased from 50% to 14.3%. A trend started to appear when comparing how the groups functioned in both cycles.

Yeah, it was all communication. Everyone needed to communicate to understand everything, and if you didn't communicate well then everything didn't work. (FGI NL1 S6)

When you're in a group you sort of get a bit off put sometimes. You get a bit distracted especially when, I don't know, because we all like had to work together sort of thing, but other people in my group don't really work. (FGI NL1 S3)

In this cycle, the groups were generally dysfunctional and poor communication was one aspect of that problem, which leads to distraction and a failure of the groups to work collectively on the problem.

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

Our group kinda [*sic*] like worked really well together because we were all friends like or became friends and we were all together we really helped each other out, and we created new friends by doing this. (FGI NL3 S1)

By cycle three, the scaffolding had been improved, and the groups worked well together on the problem and achieved an appropriate outcome. If the group dynamics are appropriate, which can be scaffolded, then the group has a better chance of succeeding in PBL.

7.2.3 Technical constraints to the use of e-textbooks to promote PBL

Technical constraints were related to infrastructure, e-textbook design and functionality. Each of these constraints had the potential to prevent students from gaining the full benefit of using the e-textbook as a tool for their learning. As such, it is important to discuss each separately to identify the problems of each one.

7.2.3.1 Insufficient technology infrastructure to support e-textbooks

Problems with the technology infrastructure in the school used to implement the e-textbook continued through all three cycles, which is not an uncommon occurrence (Chen, Gong, & Huang, 2012; Gong, Chen, Cheng, Yang, & Huang, 2013; Hamed & Ezaleila, 2015; Lee, Messom, & Kok-Lim, 2013). The main issue was that the infrastructure was unable to support multiple users so that not all of the students were able to access the e-textbook at once. This problem was evident in each of the cycles and using different delivery platforms did not alleviate its impact.

It was possible for some students to install the e-textbook onto their laptops, which meant that they did not have to access the e-textbook online. The installation of the e-textbook locally did take some of the pressure off the network. However, not all students were able to install the e-textbook owing to software incompatibility. The school's BYOD (Bring Your Own Device) laptop policy meant that a class of typical students had a wide variety of laptops, some of which were not compatible with the e-textbook. The compatibility problem was particularly the case with Apple MacBook™ and Windows 10™ machines.

BYOD has benefits for schools in that it reduces the cost of providing technology to students (Hill, 2011). However, it can be a double-edged sword since problems with compatibility and network support can emerge (Delgado, Wardlow, McKnight, & O'Malley, 2015). Both issues were apparent in this study, and no simple solution became available. Therefore, it is important to use software that is as cross-platform as possible and which reduces the stress placed on network bandwidth. The technology infrastructure in the school should support the use of e-textbooks. If this is not the case, then students become frustrated and the PBL process suffers as a result.

7.2.3.2 E-textbook design and functionality issues

While the previous technological constraint of inadequate infrastructure was an issue that could not be resolved by the researcher since it was a school-wide problem, the design of the e-textbook was integral to this study and received attention. The e-textbooks used in this study went further than the standard textbook's presentation of information to the student by facilitating PBL as they worked through the problems presented to them. Initially, the e-textbook was only a slight development beyond the traditional textbook with limited interaction and feedback. As such, it did not accomplish the task it was implemented to achieve. The platform used, Adobe InDesign™, was not sufficiently intuitive for the teacher to perform the task of providing an interactive teacher-designed e-textbook that students could use in PBL within a short timeframe.

A new platform, Matchware Mediator 9™, which was more versatile and allowed the production of more interactive e-textbooks, was used. The Matchware Mediator 9™ platform allowed for animation, audio, video and greater interaction and feedback, and the e-textbooks used incorporated these features. However, some design issues related to playing videos and saving work remained. In the focus group interviews for Newton's Laws in the second cycle, a student commented that "the videos were really small as well so if you could enlarge those videos and make them like full screen that would be really good" (FGI NL2 S5). In the Compression and Tension topic, a student commented that "if you have to exit it, make sure it is saved [because if you] go back and try to do more, then exit by the end it's just deleted all your work" (FGI CT2 S3). Improving the resolution in the e-textbook overcame the first issue and enforcing file saving when exiting the e-textbook solved the second. There were also issues relating to requiring students to engage with each page of the

e-textbook before continuing observed in the early stages of the Newton's Laws second cycle. Implementing a process that forced students to engage with each page before continuing inadvertently prevented students from moving backwards in the e-textbook as well, which later e-textbooks remedied. An attempt was also made to improve the amount of hard-scaffolding related to chemical reactions, which was largely successful, but some minor technical glitches occurred, including some equations being incorrect in the reaction generator. In developing any form of innovative design, there is the potential for unavoidable issues that only arise after implementation, despite extensive testing, which only future iterations can remedy.

In cycle three, there was one aspect of the e-textbook worthy of special mention. Note-taking was included in the e-textbook to allow students to make notes as they worked through the e-textbook (rather than using a notebook), an important feature of e-textbooks (Chen et al., 2013). The hope was that this would encourage students to make notes relevant to each problem as they worked through each step for each one. However, there were several issues with this idea. Some students were observed preferring conventional note-taking and did not use the inbuilt note-taking facility. However, when the students had to write up the results of their experiment, they then saw the benefit of having relevant notes available to them in the e-textbook. As one student stated in the Chemical Reactions topic "Yeah, and-and 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 know apply it" (FGI CR3 S2). The writing up of practical notes in the e-textbook is a PBL skill that could be incorporated in future e-textbook hard-scaffolds when introducing PBL to students.

Facilitation of the student's interaction with the e-textbook occurred in several different ways. The e-textbook assessed student understanding of various concepts and provided feedback and targeted support when needed. The e-textbook had note-taking facilities, and students also had access to glossaries in later cycles. The students had specific support tools that they could use to, for example, write chemical formulae and balance chemical equations. Improvement to such tools occurred in each successive cycle during this study. In this way, the e-textbook is superior to a standard textbook in its ability to support students in the PBL environment with a greater range of presentation media and targeted scaffolding when required.

7.3 Research Question Two: What Design Features of the E-textbook Supported PBL Intervention Most Influenced Student Learning?

The second research question concerns the design features of the e-textbook facilitated PBL intervention that most influenced student learning in a secondary school science classroom. In answering this question, it is necessary to consider the factors that enabled students to work through the PBL intervention effectively using the e-textbook. These factors were distilled from the analysis of the data and included facilitation features, interaction features and enjoyment.

7.3.1 Facilitation features that influenced student learning when using e-textbooks to promote PBL

Facilitation features covered some different categories that included: practical focus, hands-on, self-paced, multimodal, argumentation and PBL. These factors can be coalesced into two main categories: problem design and e-textbook design. The number of facilitation features increased as the study progressed.

7.3.1.1 Problem design

All of the problems presented in the e-textbook had to relate to the Australian National Curriculum document (ACARA, 2016). These problems covered areas of the Chemical and Physical Sciences. The design of problems in PBL is axiomatic to the successful process of PBL in students (Sockalingam, 2015). However, the nature of the problems used in PBL is a broad church with many areas of contrast. Sockalingam and Schmidt (2011) categorised the features of problems into 11 categories (see Figure 7.4). The features described by Sockalingam and Schmidt (2011) are useful because they focus on the design of the problem and the intended results of working on the problem. As such, it is important to consider these features since they apply to the iterations conducted in this study. The format of the problem is the way it is presented to the students and includes “titles, clues or keywords, analogies, metaphors, stories, and pictures” (Sockalingam & Schmidt, 2012, p. 160) to facilitate PBL in students. The format evolved during this intervention to improve the way in which students interacted with the problem. Figure A2.8, A2.9 and A2.10 show the development of the problem format. Initially the format involved text with keywords defined and a few pictures and two videos. Later iterations included animation, video, audio and animations to present the problem to students.

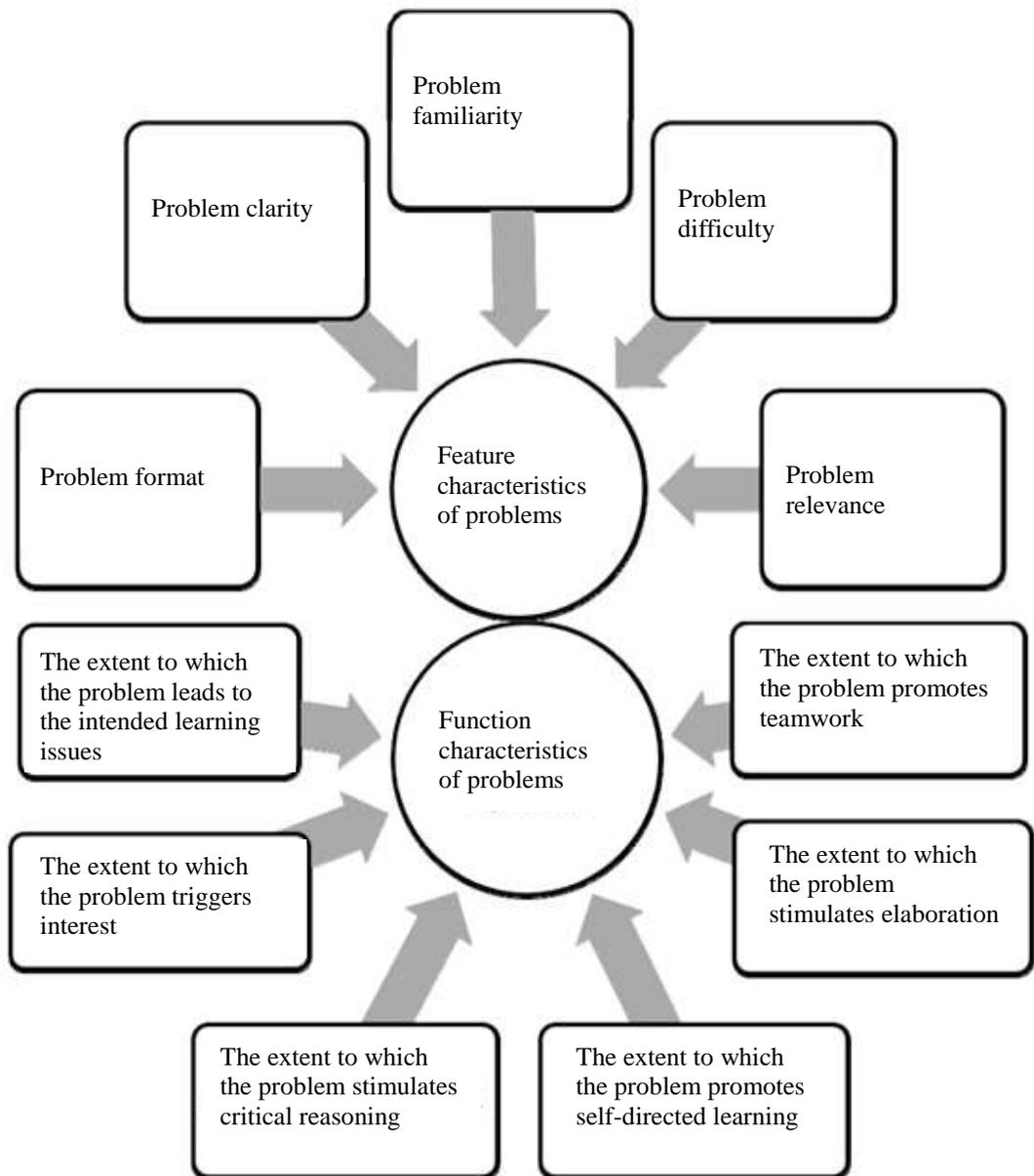


Figure 7.4. Feature and function characteristics of problem design (Sockalingam & Schmidt, 2011, p. 21).

Problem clarity is an important aspect of problem design and relates to the students' understanding of the problem presented to them (Sockalingam, Rotgans, & Schmidt, 2011). To provide clarity to students regarding the problems presented to them, the VARK model was used (Fleming, 1995). This model utilises different ways of communicating information: visual, aural, reading and kinaesthetic. Initially, the main styles utilised were reading and kinaesthetic. Reading related to the use of

information in the form of text, and kinaesthetic related to the manipulation of equipment used to work through the problem with some visual information included, but this was an adjunct to the text information. As the study progressed, the e-textbook included all styles of the VARK model.

Problem familiarity is a “prior understanding and knowledge of the problem” (Scott, 2014, table 1). Familiarity with the problem poses a dilemma. If a problem is too familiar, it may not improve academic outcomes (Soppe, Schmidt, & Bruysten, 2005), but there is a negative relationship between problem familiarity and student learning (Scott, 2014) where “students are unable to relate to them” (para 14). However, Sockalingam and Schmidt (2012, p. 158) noted that an unfamiliar problem “stimulates significantly more questioning, thinking and reasoning than the familiar problem.” The problems provided to students were designed to have some aspects familiar to them. The Newton’s Laws iteration assumed that students would have some familiarity with rockets, and additional information was supplied to them to bridge the gap between what was familiar to them and what they needed to learn. Since the problem involved designing a model rocket, a video of a model rocket in flight was used (see Figure A2.12). Later, the presentation included a better video that was related more to the design of model rockets rather than the problems encountered with life-size rockets and more explanation of what was occurring in the video (see Figure A2.13). The improvements were made to relate the information more closely to the problem and provide the students with visual clues to which they could relate to their experiences.

Problem difficulty relates to a variety of factors, and some of these factors are beyond the control of problem developers to manipulate (Jonassen & Hung,

2008). Moreover, many of these factors interrelate to produce a complex ecosystem in which it is difficult to determine cause and effect. However, some speculation about the interaction of some aspects of problem difficulty is possible based on published findings, which is relevant to the consideration of problem design in this study. Figure 7.5 shows some interrelations as described, by (Sockalingam & Schmidt, 2012), and some possible interrelationships between the various characteristics problems used in PBL. It is reasonable to expect that the clarity and familiarity of the problem will affect a student's interest in the problem since students will be less likely to engage with a problem with which they have no commonality, or which is obscure to them. However, issues with clarity and familiarity only scratch the surface of the complexity of the interactions when considering problem difficulty in PBL. If problem difficulty is expanded to take into account the aspects described by Jonassen and Hung (2008), then the complexity of the ecosystem increases, but is also more illuminating as to how problem design affects PBL (Figure 7.6).

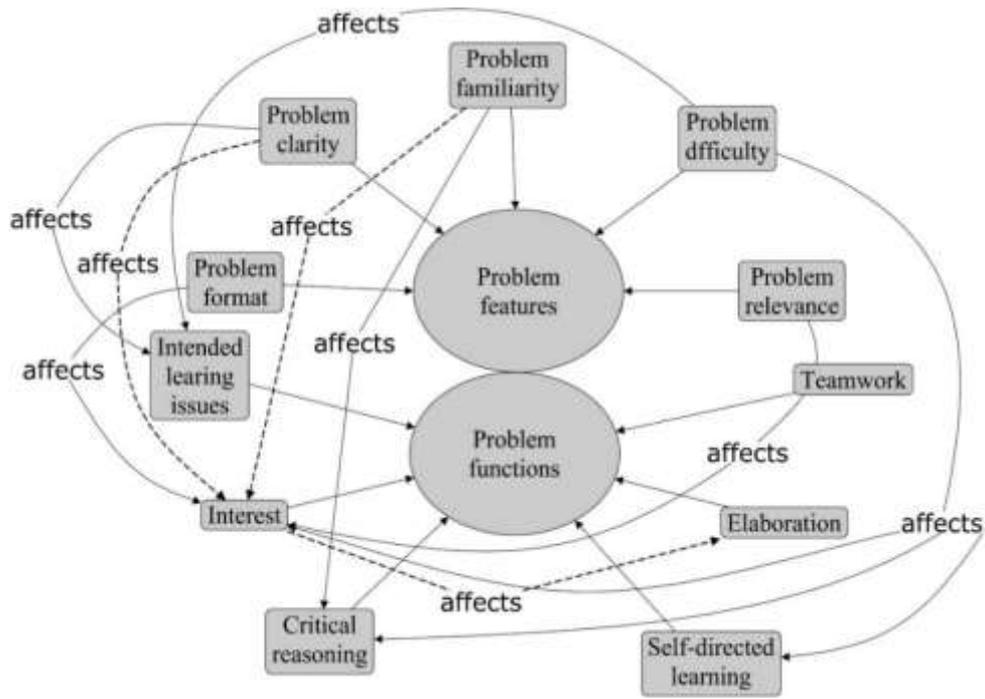


Figure 7.5. Interrelationships between various problem design features (Sockalingam & Schmidt, 2012). Described (—) and speculated (---).

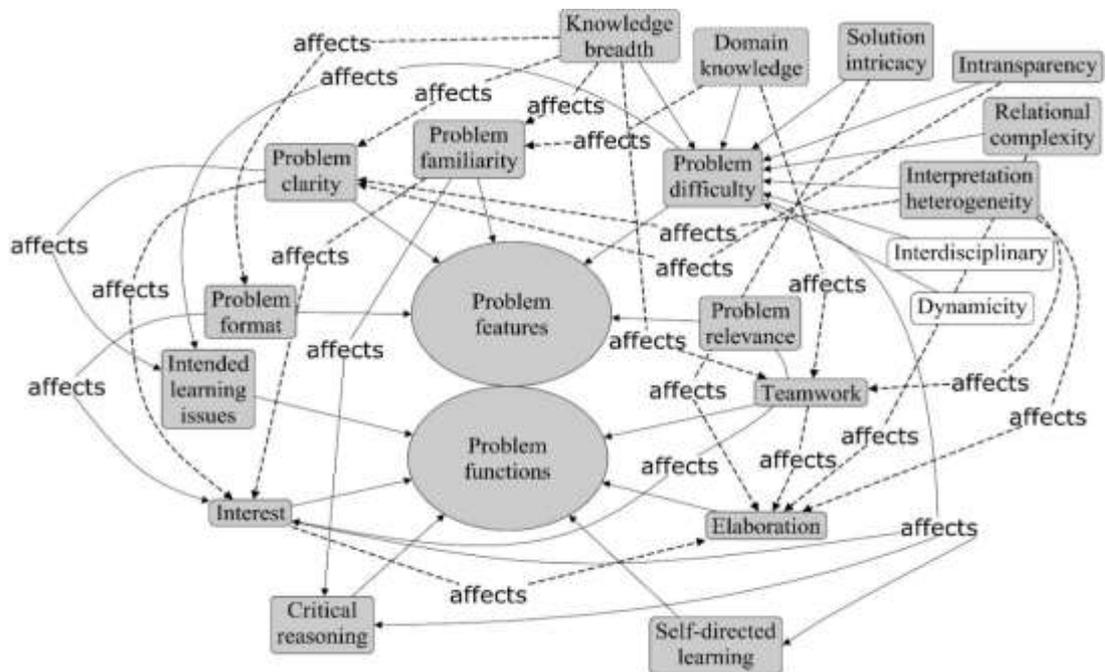


Figure 7.6. Interrelationship between various problem design features (Sockalingam & Schmidt, 2012) and aspects of problem difficulty (Jonassen & Hung, 2008). Described (—) and speculated (---).

The breadth of knowledge required of the students in all the problems was limited to a few concepts in each one. In Newton's Laws, for example, the concepts the students required knowledge about were inertia, forces (balanced and unbalanced), mass, acceleration and velocity with only some knowledge required in each problem. In the Chemical Reactions topic, the students required an understanding of chemical reactions, formula and equation writing and kinetic theory. In this case, each problem required most of the concepts. In the Compression and Tension topic, the concepts were limited to compression and tension. The breadth of knowledge required did not vary during this study. It is not unreasonable to link the required breadth of knowledge to the clarity as well as familiarity of the problem and to consider that the limited knowledge required compelled the designer to make the problems clear and familiar.

Domain knowledge related to how difficult the concepts covered in the problem were for students to understand (Jonassen & Hung, 2008). While the breadth of knowledge students required was limited, some of the concepts covered were challenging. Thus, concepts had to be presented to the students in a way that provided them with the means by which to comprehend the concepts effectively. In the Newton's Laws topic, for example, the number of concepts was low, but they were difficult to apply. Initially, Newton's Laws were considered all at once regarding presentation, investigation and review (see Figure A2.8). The domain knowledge of the students was not sufficient to work with the limited information presented to them. A quote from a student during the first Newton's Laws topic illustrates this point:

This is hard because I have no idea how to build rockets. Just to know like what we're actually sort of doing, because I think it was more like we had to

go through the book sort of thing and then we were put on this program and I had no idea how to do that. (FGI NL1 S3)

Later, the students had more information provided to them that they would then have to apply to each of the problems (see Figure A2.14). For example, the mathematical applications that students would need to be able to apply to the problems (see Figure A2.15 and A2.16). As a result, students showed an improved understanding of how to apply these concepts to the problems encountered in the Newton's Laws topic and this improvement was attributable to greater problem clarity, familiarity and improved teamwork seen in cycle three. Two quotes from the Newton's Laws topic in cycle three illustrated this point. The first quote showed that students had shifted away from just memorising facts (definitions) and focused on using the equations from Newton's Laws that were applicable to the problem. The second quote confirms this application of ideas to real life, in this case, the rocket design.

I learnt more about the equations more I didn't really focus on the information and usually we like have definitions we have to know for the test like we didn't really focus on that we focused more on the equations and finding those results and the practicals. (FGI NL3 S2)

I think I learnt more especially like with the pracs and everything like helping to like fill in everything and actually like put it into real life. (FGI NL3 S4)

Both students also commented on how they worked in their respective groups, confirming the improved teamwork.

Our team was really good because we're like friends and we worked really well together. (FGI NL3 S2)

Yeah, our team was like had different like everyone had like different like opinions and ability and personality so it worked really well and I suppose the group working it is good coz [*sic*] it doesn't change. (FGI NL3 S4)

In the Compression and Tension topic, there were only two main concepts. However, they were difficult to apply to various situations. To assist students with applying these concepts to the problem, they were presented with animations to show them how the concepts of compression and tension applied to the problem they were considering, which was to build a bridge. Their application of these concepts was augmented further by showing students how to determine compression and tension forces before finally presenting them with the problem (see Figure A2.17). However, this did not help students in their application of these concepts to the problems encountered. When asked in a focus group interview for the Compression and Tension topic about what they learned about the topic, all of the students commented that they did not learn much about the content. The students had difficulty visualising how to solve the problem of building a bridge. One student commented that:

It was hard to try to figure out how to do the design of the bridge just without actually building at the same time. We had to do the design before we could build it and we had to figure out if we had enough resources to make it work. (FGI CT2 S2)

Another student noted the difficulty they experienced in design the bridge before actually constructing it:

We didn't get to see our resources before we actually made a bridge, we knew what we were getting but we didn't like actually trial stuff. (FGI CT2 S1)

Therefore, it was difficult for the student to work in the abstract with these concepts, preferring to construct the bridge through trial and error.

The intricacy of the solution to the problem, which has been termed the solution path length, is dependent upon the amount and difficulty of the tasks required to be completed to solve the problem (Jonassen & Hung, 2008). The more

intricate the solution (the more complex it is regarding its difficulty and number of tasks), the more the students will need to elaborate on the concepts covered.

However, there is a point at which the intricacy of the task can be so great as to work against elaboration. Most of the problems encountered by the students in this study had a similar number of tasks, and the number increased only in the final problem of each iteration. The complexity of the tasks is a more nebulous concept. Does writing a balanced chemical equation for a decomposition reaction equate with determining the acceleration of different masses using a formula? While students exhibited varying levels of understanding in most topics, the most difficult was the Compression and Tension topic where there were a similar number of tasks to be completed but their overall complexity, for example in bridge building, was more challenging.

Relational complexity refers to the number of factors that interrelate (Halford, Wilson, & Phillips, 1998). The level of relational complexity was variable across each topic. For example, in the Newton's Laws topic there was considerable relational complexity. Students needed to relate displacement and time to determine velocity. Velocity was then used to calculate acceleration, which, in turn, was used to calculate force at various masses (see Figure 7.7). There was an increase in the support the students received regarding how each of the factors related to the others, and this aided their application of the concepts to each problem, which helped them to elaborate on the topic regarding how factors interacted. When students were asked to apply Newton's Second Law to a practical problem, 46% could do so correctly prior to the iteration compared with 58% at the conclusion of the iteration. In the third cycle, the results for correctly applying Newton's Second Law were 70% before the cycle compared with 80% at the conclusion. When asked to describe an example

of Newton's Second Law, 17% of students before the first cycle and 14% at the conclusion of that cycle could do so correctly. However, it is important to note that this was because of their not including all of the necessary information in their answers. The number of responses that contained misconceptions decreased from 52% to 23%. The inability of students to provide all the information necessary may have related to the relational complexity of the problem. The students were not able to consider all of the factors in Newton's Second Law. In the third cycle, 12.5% of students could correctly describe an example of Newton's Second Law prior to commencing the cycle compared with 44% at the conclusion. While not dramatically improving, there is an upward trend in student's ability to describe and apply Newton's Second Law with improved support in cycle three in terms of the presentation of the problem to the students.

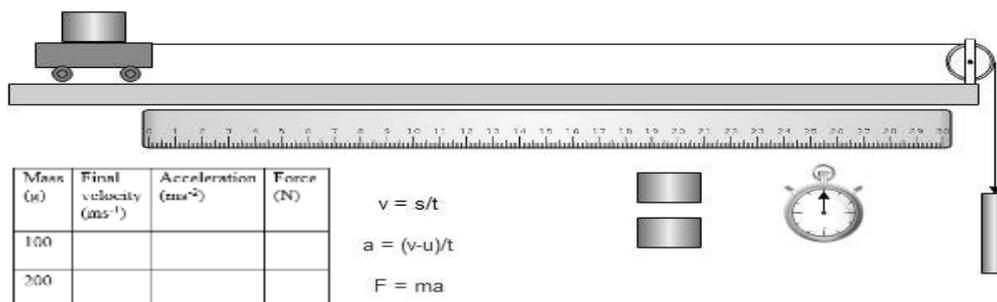


Figure 7.7. Representation of one group's solution to the problem of establishing Newton's Second Law showing the concepts that need to be related.

In the Chemical Reactions topic, the students needed to understand the concept of chemical reactions at the microscopic (molecular) level rather than the macroscopic level seen in the Newton's Laws topic. Initially, the students received very little information at the molecular level about what was happening (see Figure A2.18). The amount of information was later increased to include a large amount of detail, at the molecular level, about how molecules interacted (related to each other) in decomposition reactions before and after the problem was completed (Figure 7.8).

The figure consists of three vertically stacked screenshots from a chemistry simulation interface, each with a callout box on the right. The interface features a character in a red shirt and a laboratory setting.

- Top Screenshot:** Titled "Chemistry problem 1". A callout box points to a video on a screen showing a decomposition reaction. The text in the callout box is: "Students presented with a video of decomposition reaction".
- Middle Screenshot:** Titled "Chemistry problem 1". A callout box points to a diagram of two test tubes on a stand, illustrating decomposition reactions at a molecular level. The text in the callout box is: "Students presented with an explanation of decomposition at the molecular level".
- Bottom Screenshot:** Titled "Problem 1 review". A callout box points to a beaker containing a reaction mixture. The text in the callout box is: "Review of problem one presented to students at a molecular level". The beaker is labeled "Adding copper sulphate to water" and lists the substances: Water, Copper sulphate, Sulphate ion, and Copper ion. Below the beaker are buttons for "Periodic table", "Compound generator", and "Reaction generator".

Figure 7.8. Screen shot from the Chemical Reactions topic showing the information provided to students in cycle three, iteration two.

The increased detail enabled the students to understand the relationship between molecules in each of the problems studied, which, in turn, made elaboration of the topic easier. When students were asked to explain the melting of an ice cube in cycle one of the Chemical Reactions topic, 6% of students prior to the iteration could do so correctly, and 0% could do so at the conclusion of the cycle. In the third cycle of the Chemical Reactions topic, the results were 30% and 50% respectively. In the third cycle of the Chemical Reactions topic, the explanation, at the molecular level, of the reactions was more detailed and students were able to describe changes at the molecular level more accurately. When asked to explain how a particular factor (e.g., temperature) affects reaction rate in cycle one of the Chemical Reactions topic, 0% of students prior to the cycle could do so correctly and 20% could do so at the conclusion of the cycle. In the third cycle of the Chemical Reactions topic, the results were 25% and 44% respectively. Again, students were able to explain the effect of the factor at the molecular level.

Intransparency refers to the amount of unknowns in a problem. Jonassen and Hung (2008) use the example of weather forecasting to illustrate a problem with high intransparency. There are many unknowns with unidentifiable effects. The level of intransparency was low in each of the problems the students encountered. While the relationships between various factors were unknown to the students, the factors themselves were known to them or made known. As a result, intransparency should not have interfered with the clarity of the problem.

Problem heterogeneity refers to the number of ways that the student can understand the problem (Jonassen & Hung, 2008). The level of heterogeneity was low in each problem with only a very limited number of ways for understanding the problem. The low heterogeneity would have aided problem clarity but hindered

teamwork and elaboration since there was a reduced need for discussion of various solutions that would require less elaboration. The level of interdisciplinarity and dynamicity were not relevant to this study because there was no opportunity for students to use multiple disciplines to solve the problems and factors were not dynamic regarding the actions of the student or each other.

Problem design changed throughout this study in response to observations and student responses to the problems. For example, in the first cycle of Newton's Laws and Chemical Reactions, students had difficulty applying knowledge from the initial problems to the final one. In the Newton's Laws topic, there was not sufficient development of the concepts required to engage with the final problem successfully. In the Chemical Reactions topic, the initial problems lacked appropriate support for students to engage with them. Each problem needed to be able to be analysed by students, so they could plan a solution in their groups by conducting appropriate research and applying prior knowledge to produce testable hypotheses. The problems needed to be sufficiently structured so that students could work towards a solution, but not so structured to provide an obvious answer. In this study, it was preferable to use several small problems that interlinked particular concepts and skills rather than one large problem that did not allow for the development of skills or comprehension of concepts covered owing to too many concepts applied at one time. The result of the problem while important was not the main focus; it was the journey as well as the destination that was important. There was a change in the students' attitude in the Chemical Reactions topic between cycle one and three that illustrated their change in attitude to the practical (problem) work with the use of the problems that provide knowledge rather than notes:

But I did find that when I do note-taking, like and it shows in my test results from both methods, that I do a lot better that I find that it is easier when it comes to a test I actually know what it's going to be on like I can study it. (FGI CR1 S1)

I feel like with chemistry it's much better to have the more practical side because it's all about the reactions and what makes them, so it's better to actually see it than just write it down. (FGI CR3 S5)

The practicals make it interesting and sort of confirm your understanding. (FGI CR3 S4)

7.3.1.2 E-textbook design

While the problems presented to the students in a PBL experience assume a place of prime importance, the mode of delivery to the students was an equally important aspect of this study. The e-textbook was designed to be a platform for which students were not only presented with a series of problems to work on, but also to help facilitate their development of problem-solving skills. Therefore, it is important to consider how the e-textbook's design evolution assisted students in their PBL journey.

Use was made of the VARK model (Fleming, 1995) in the design of the e-textbooks to varying degrees in each iteration to present problems and problem-solving skills to the students. In the first iteration, the main modes utilised were reading and kinesthetic with the remainder of the modes incorporated in cycles two and three. The simplistic nature of the e-textbook's presentation of the problem and problem-solving skills to the students in cycle one meant that it was of limited use to them. As such, the students did not find the e-textbook particularly helpful since, while there was a hands-on approach to the problem, there was not a true multimodal presentation of ideas. The multimodal aspect was developed in the second and third cycles and was an enabling factor for students using PBL and

developing problem-solving skills, especially in cycle three. Students were continually observed using the animations, videos and cognitive tools during lessons while working on the problems.

Students could work through the e-textbook at their own pace. However, it became necessary in cycles two and three to constrain student progress. Students were apt to proceed too quickly through each page without stopping to engage in the concepts presented fully. Student progress was limited in two ways to ensure that they engaged fully with the concepts presented. In some cases, students could not move on to the next page for a certain time interval, and in other cases, they had to complete a particular evaluation of a particular skill before continuing. The control of student progress through the e-textbook helped to ensure that they engaged with and understood the concepts presented to them.

Traditional textbooks do not control a reader's progress through the information provided to the reader. The reader may refer to previous pages or skip ahead to points in the book. In designing the e-textbook, the former of these two habits is to be encouraged as it allows students to review past information to consolidate or confirm understanding of key concepts. The latter habit, however, should be avoided. In the first e-textbooks, students could move freely through it, which meant that they could skip through sections of the book that were important. Therefore, they missed key concepts that they needed to work on the problems presented to them later. It was, therefore, important to control the students' movement through the e-textbook by allowing them to move backwards for review but preventing them from skipping forward and missing important information.

7.3.2 Interaction features that influenced student learning when using e-textbooks to promote PBL

Interaction features covered two different categories: feedback and group-work. Each of these features influenced how students learned through the process of PBL and were facilitated by the e-textbook. Although these two features are interlinked, each feature will be considered separately.

7.3.2.1 Feedback

Students needed to be able to interact with the e-textbook in a purposeful way that supported their learning in a PBL environment. This interaction was always intended to be two-way, with the students receiving feedback from the e-textbook as they worked through it. Initially, this feedback was limited to correcting student responses to a multiple-choice questionnaire with feedback on why their answer was right or wrong (see Figure A2.19). Furthermore, this feedback did not cover PBL.

Subsequently, the level of feedback was improved to include targeted feedback to students in specific areas where they needed further support. Students received feedback about each of the problem's concepts that they completed before starting the next problem as well as PBL (see Figure A2.20). Students received targeted support about PBL as well, which linked to their responses to the questionnaire they completed (see Figure A2.21) This support assisted students by providing them with needs-based support for working in a group in a PBL environment. Students commented on this feedback in the focus group interviews:

Better because we have like a normal you've done all these questions, but you don't even know if it's right or not, and there's like no answers at the end of the book or anything, so that was good because it like ticked off whether you got it right or not. (FGI NL1 S3)

And in the e-text book if you get one wrong it would cross, but it would tell you what was wrong about it and they sort of give a small little hint about

what one's right and what one's wrong, and that was a lot better than just trying to figure it out yourself. (FGI NL1 S3)

The provision of feedback in all areas of PBL is important. Incorporation of specific feedback that is responsive to student needs is an area that requires careful attention when designing e-textbooks for PBL. Such differential feedback means that individual differences within groups are, to some extent, catered for in the e-textbook.

7.3.2.2 Group-work

PBL classes operate in groups with learning occurring at the small group level rather than the whole class. However, productive group interaction does not just happen when students are brought together (MacQuarrie, Howe, & Boyle, 2012), but rather, it occurs as the result of a deliberate set of acts on the part of the facilitator (Frey et al., 2009). To move from a group of students sitting together to a group of students interacting with each other to learn together, it is necessary to upskill them in the specific requirements of working as a group in a PBL classroom.

An initial assumption was that students already knew, from previous exposure to group-work, that they would work effectively in groups. This assumption proved to be erroneous with group dysfunction contributing to a lack of learning in each of the groups. Furthermore, students were permitted to choose their groups, which impeded interaction within the group rather than supporting it. Thus, for example, there might be four students in a group, but not interconnecting with each other for PBL:

I think coz [*sic*] some people got confused by it and didn't understand they just they didn't contribute to it very much, so some people just decided to forget about it and let other people do the work in that group. (FGI NL2 S4)

For a group to successfully engage in PBL, it is necessary for individuals to be able to listen and respond to each other, allocate tasks on an equitable basis, research the problem and provide reasoned arguments for their solution. In this scenario, rather than just butting together, the group fits together like a jigsaw (see Figure 7.9). To achieve this, support for group-work was included in the e-textbook. However, students could move ahead in the e-textbook without fully engaging in the concepts presented. Subsequently, students were made to engage with the material presented, rather than skipping over it and this had the effect of at least ensuring that they were aware of material concerning effective group-work. While this design feature did not completely solve the problem of developing effective group dynamics, it did raise the baseline of student interaction as the quotes from the focus group interview indicate:

Our team was like had different like everyone had like different like opinions and ability and personality so it worked really well and I suppose the group working it is good coz [*sic*] it doesn't change you but [you] build relationships. (FGI NL3 S4)

It kinda [*sic*] pushes you but coz [*sic*] 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)

The result was that the facilitator had more time to devote to providing each group with targeted support as and when needed instead of concentrating on group cohesion.

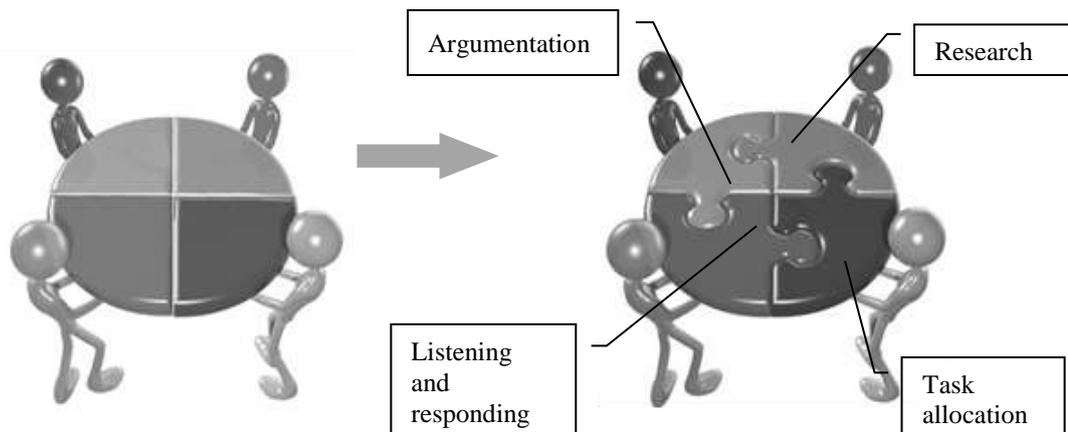


Figure 7.9. The shift from students in a group to students working as a group by listening and responding, allocating tasks, researching and engaging in argumentation. Image source: thegoldguys.blogspot.com/

The method of assigning students to groups also changed during the study. Initially, grouping occurred on a friendship basis, which was not productive. Randomly assigning groups did not improve the situation. However, when group assignment was random in a class of mixed ability, the most productive groups resulted since those who could grasp concepts quickly could explain these to group members who were experiencing difficulty with their understanding of these concepts. Furthermore, by explaining their ideas to other students and having those students then question their understanding, there was argumentation, which assisted the group's understanding of the problem solution as the following quotes from the focus group interview indicate:

I found that with the last program that we did, I was in a group that was like majority my friends, I found I did the work a lot of the work myself like they would kind of talk and I would be doing a lot of the work ... But this one was we all played a part, and it was a lot better. (FGI CR1 S3)

It was a lot like you could divvy up the work a lot easier so you could sort of he could sort of focus on something and I could focus on something then we could just collaborate it, and it would be a lot more efficient way of learning. (FGI CR1 S2)

If you didn't know stuff you could just ask other people in the group. (FGI CR1 S5)

7.3.3 Enjoyment features that influenced student learning when using e-textbooks to promote PBL

Enjoyment influences how students learned through the process of PBL, and PBL positively influences their enjoyment of science (Ferreira & Trudel, 2012). In the Newton's Laws topic, the student's enjoyment related to the final part of the problem, which was the construction of a model rocket to illustrate Newton's three laws of motion. The intent had been to develop their understanding of Newton's Laws and then have the students apply them to the design of the rocket. However, this did not occur, and the rocket design became all-consuming and was a result of the e-textbook design overemphasising the rocket design and not developing Newton's three laws sufficiently. Giving greater emphasis to Newton's Laws and the design of the model rocket less emphasis resolved this issue. Each of Newton's Laws became a problem and the rocket design a separate problem. There was an appreciation of the importance of each problem as students no longer identified the rocket as the only part of the PBL experience they enjoyed. Quotes from the Newton's Laws focus group interviews in cycle one and three illustrate this change. In cycle one a student commented that:

Well I definitely liked building the rockets, but I think filling out the workbook we might have sort of got off the topic a bit, and it was sort of wasn't really done in a proper way where we all really worked together. (FGI NL1 S4)

The comment indicates that the building of the rocket was the main attraction for the student. In cycle three, two students commented that:

Like through the experiments [problems] I actually understood like usually, I read something, and I just have to like remember what it says, but I actually understood the process better by doing this. (FGI NL3 S2)

I think I learnt more especially like with the practicals and everything like helping to like fill in everything and actually like put it into real life. (FGI NL3 S4)

The students appreciated all of the problems (experiments/practicals), and they considered the rocket design as part of the whole PBL experience. The change in attitude was due, in part, to the length of time available for each problem since the amount of time for the design and construction of the rocket was reduced in cycle three to limit its overall significance again. Furthermore, students could no longer skip over the first three problems and so gained a greater understanding of their importance to solve the last problem.

In each of the other topics, enjoyment either increased or remained the same. In the Compression and Tension topic, there was more of a practical focus, which the students enjoyed despite the concepts themselves being more esoteric in nature (Table A1.54). In the Chemical Reactions topic, the increase in enjoyment related to the practical nature of the problems in cycle one (Table A1.38). Making the Chemical Reactions topic problems more challenging, albeit with more support, regarding what the students had to understand resulted in a reported diluted enthusiasm of the students for the practical work, which accounts for their enjoyment not changing in cycle three. Turner, Ireson, and Twidle (2010) reported that the complex nature of chemistry experiments was one reason students did not enjoy the subject. As one student commented in the focus group interview for Chemical Reactions in cycle three:

Personally I'm not a big chemistry fan so the whole the topic in general wasn't my favourite thing. (FGI CR3 S1)

However, this was not a universal impression. Two other students commented that:

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

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 know apply it. (FGI CR3 S2)

It is difficult to reconcile the two opposite ideas, but it may be that the students expectations of the Chemical Reactions topic were not affected by the PBL experience and students that like chemistry and those that disliked chemistry did not change their opinion.

7.4 Research Question Three: What was the Overall Impact of the E-textbook Supported PBL Intervention?

The third research question concerns the overall impact of the e-textbook intervention on student learning through using a PBL program in a secondary school science classroom. In answering this question, it was necessary to consider the areas in which the e-textbook had the greatest impact. This study focused on three main areas that were of interest in PBL: content knowledge; planning, monitoring and evaluation; and student engagement. Content knowledge involved learning specific concepts and applying what they have learned to new situations. Planning, monitoring and evaluation concerned how well students could transfer skills from one problem to another in terms of organising their approach to the problem,

examining their progress and determining how well they performed while working on the problem. Student engagement examined how students participated in the PBL exercise and worked as a group.

7.4.1 The impact of the e-textbook intervention on student knowledge

In the context of this study, student knowledge is defined as content knowledge and application of that content knowledge. As students worked on problems, they moved from the initial state to a goal state along a solution pathway. The initial state is defined as “what is known” (Jonassen, 2000, p. 67), how the problem-solver understands it (Jonassen & Hung, 2008) and is a starting point (Pretz, Naples, & Sternberg, 2003). It is from this point that a student, as part of a group, will move down a solution pathway. The solution path is a “series of discrete transitions in a maze” (Ericsson, 2003, p. 39), “the problem-solution process” (Jonassen & Hung, 2008, p. 10) and “sequences of solution steps students” use to reach the goal state (Rivers & Koedinger, 2014, Related Work, para 1). The goal state is “what is trying to be achieved” (Jonassen & Hung, 2008, p. 13), an end point (Greiff, Holt, & Funke, 2013; Pretz et al., 2003) and a “well defined solution” (Jonassen, 2000, p. 67). These steps are together considered the problem space (Schwarz & Skurnik, 2003). In this study, students’ content knowledge did not significantly improve in cycles one or two (Figure A1.1, A1.2 and A1.16). In cycle three, the students content knowledge did significantly improve in both iterations: Newton’s Laws and Chemical Reactions topics (Figure A1.3 and A1.17).

It is in this problem space that students worked as a group to develop a solution to the problems presented to them in the e-textbook. Bogard et al. (2013) created a model that described 13 cognitive processes used by advanced learners

working on complex problems. Their model has been adapted to define the problem space as it would exist for less advanced learners (secondary school students) working on less difficult problems (Figure 7.10). This model is used to describe the development of the students' knowledge as they worked through the e-textbook problems. When the students first encountered each of the problems, their initial response was to analyse the problem. In the first cycle, this was not well supported by the e-textbook. Students were asked to explore the topic regarding terms, concepts and issues with minimal prompting (Figure A2.22). The lack of scaffolding from the e-textbook made analysing the problem too difficult as students did not have a means by which to access any relevant prior knowledge that may have been useful in the analysis of the problem. The students were then provided with some background information and asked to write down what they knew about the problem (Figure A2.22). The student's responses commonly included statements such as "I do not know anything about this" or "what do I write?" Students were seemingly unable or unwilling to write down any information they considered relevant to the problem. Predictably, when students were asked to write down what they did not know they responded with "I do not know what I do not know" or "I do not know anything."

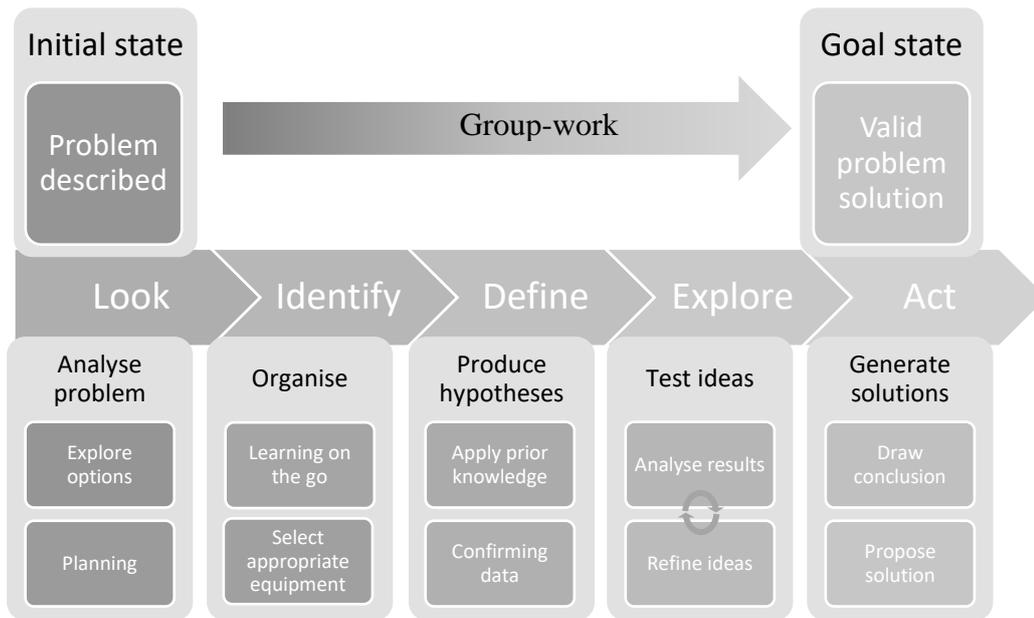


Figure 7.10. A description of the problem space from the initial state to the goal state based on Bogard et al. (2013).

Bogard et al. (2013) described the initial steps in problem-solving as orientation, which involves using cognitive tools and planning to develop ways of finding information. In the adaptation of this model, the first step is an analysis of the problem (Figure 7.10). In the first cycle, students were not able to orient themselves or plan any meaningful strategy to find information since the cognitive tools provided to them were insufficient.

These cognitive tools are “technology-based tools serv[ing] as scaffolds in learning environments” (Bogard et al., 2013, Introduction, para 4) and which are used by the students. Therefore, a large amount of soft-scaffolding was needed to compensate for the lack of these cognitive tools. Providing better cognitive tools to the students (Figure A2.9), alleviated the dependence on soft-scaffolding. There was an increase in the number of cognitive tools and their placement in the e-textbook. Students had more information about the concepts, and there was a review of these concepts at the end of each problem in the e-textbook. Students were then able to

plan more effectively to obtain information. For example, in the first problem of Newton's Laws (cycle two, iteration one) the students could effectively plan a means of data collection (Figure 7.11).

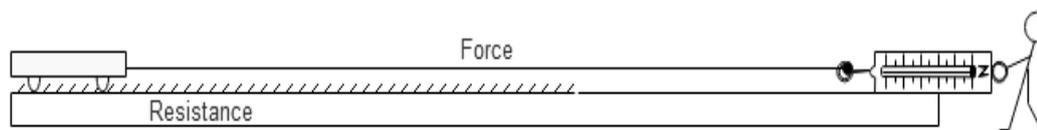


Figure 7.11. Representation of one group's solution to the problem of establishing Newton's First Law showing the factors that need to be identified.

However, prior knowledge about conducting controlled experiments was not activated, which made comparing data meaningless in this situation (Figure 7.12).

When the students attempted to test their ideas using different resistances, their analysis lacked a baseline for comparison. In refining their ideas, they then saw the need for a control that produced their baseline data, which allowed for hypothesis formation. However, they were unable to produce a satisfactory solution to the problem. This led to an improvement of the design of the cognitive tools ability to activate prior knowledge about controlled experiments (Figure A2.10). The students were then not only able to conduct a controlled experiment (Figure 7.13) but were able to propose a solution to the problem.

A similar problem arose in the Chemical Reactions iteration. Initially, there was minimal provision of cognitive tools to the students (Figure A2.18). The result was that students were not able to analyse the problem effectively to plan a solution and so again a large amount of soft-scaffolding was necessary. The cognitive tools available to the students were significantly increased in later cycles (Figure 7.2 and 7.8) resulting in the students being able to analyse the problem, organise the

equipment, apply prior knowledge and test their ideas. This led to a successful solution to the problem, which indicated that students had a deeper understanding of

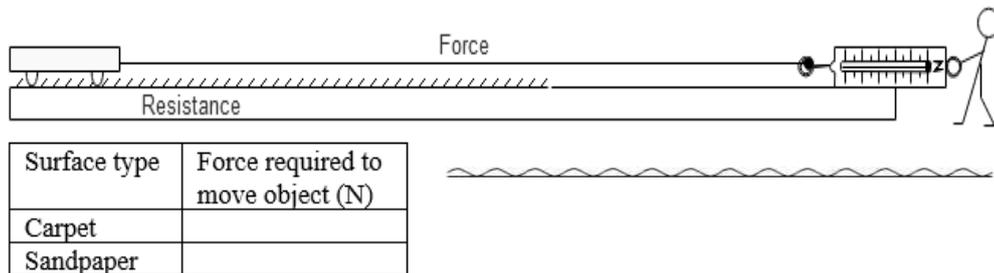


Figure 7.12. Representation of one group’s solution to the problem of establishing Newton’s First Law showing the factors that need to be measured.

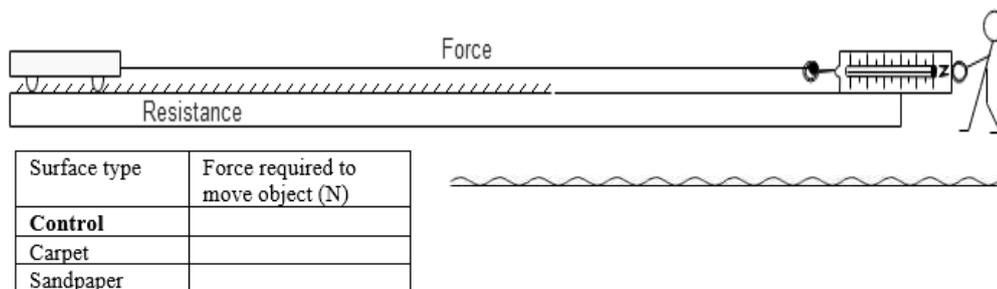


Figure 7.13. Representation of one group’s solution to the problem of establishing Newton’s First Law showing the factors that need to be measured and compared.

the concepts as also evidenced by classroom observation (Table A1.1 and A1.41).

7.4.2 The impact of the e-textbook intervention on problem-solving transfer

Problem-solving transfer is defined as occurring “when a person uses previous problem-solving experience to devise a solution for a new problem” (Mayer & Wittrock, 1996, p. 47). Mayer and Wittrock (1996, p. 49) described four different types of problem-solving transfer: general transfer of general skills, specific transfer of specific behaviours, specific transfer of general skills and metacognitive control of

specific and general strategies. It is the fourth type of problem-solving transfer that is most relevant to this study because it involves selecting previously acquired skills, applying those skills to the new problem and considering their usefulness or otherwise in solving that problem as they progress (Mayer & Wittrock, 1996).

To determine how well students transferred their problem-solving skills to new problems, it was necessary to consider their planning, monitoring and evaluation regarding the model used to describe the impact of the e-textbook (Figure 7.10). These are domain-general skills that apply to any problem. Examination of how students planned their analysis of the problem (Table A1.7 and A1.31) showed a change in their approach to problem-solving in some areas as they moved from the first problem to the second problem. There was more emphasis placed on background reading and less emphasis on prioritising learning needs by the students between the first and second problems. Students needed more information to make sense of the problem presented to them. Allocation of resources remained important, and allocation of group members to tasks became less important. In all cases, there was a limited amount of resources available to students as the study progressed, and so these had to be allocated carefully and planned in advance. Allocating group members to tasks became less important as students largely used who was best suited or interested, an approach that had worked for them in the first problem.

In evaluating each step in the solution to the problem, students had a variety of different strategies, but in the third cycle, they used fewer strategies in both topics (Table A1.10 and A1.33). The improvements to the e-textbooks scaffolding to support the students working on the problems resulted in their using fewer strategies more effectively rather than a shotgun approach (Table A1.20 and Table A1.41).

Students had a variety of evaluation strategies (Table A1.12 and A1.34), including progress and the end result. It is difficult to provide a rationale for this change and may simply reflect individual student preferences.

In the Newton's Laws topic, students had to transfer ideas learned about Newton's three laws to the design of a rocket. The problem provided an example of far transfer since the problem was not familiar to the students and required the application of concepts to a nonroutine problem with more conscious effort (Jonassen, 2000). Initially, students found this very difficult with the designs of their rockets showing little improvement over the course of the iteration (Figure A2.23 top). The students had access to a cognitive tool in the form of the OpenRocket software program that allowed them to design and test their rocket designs. The use of this software was hard-scaffolded into the e-textbook, but students still found the program difficult to use. The students did not effectively apply what they had learned about Newton's Laws to the design of their rockets. An improvement in the presentation to the students of each of Newton's Laws and the soft-scaffolding of the use of the OpenRocket program did not lead to an improvement in the students' rocket design (Figure A2.23 middle). The e-textbook was modified to present students with specific concepts about the first three problems they worked on so that they could consider them in the design of their rocket. The e-textbook design change resulted in an improvement in the design of their rockets with students considering specific modifications (e.g., fin shape and nose cone shape) in their final designs (Figure A2.23 bottom).

In the Chemical Reactions topic, there was a similar far transfer required of the students. In the first problems, the students encountered regarding the different types of chemical reactions, the students needed to observe evidence of specific types of chemical change occurring. In the final problem, which involved factors affecting the rate of chemical change, there was a change from observation to measurement. Students did not understand this change and relied on observation in this problem as well. The students could conduct a controlled experiment with accurate measurement of the reactants and consider how to change the independent variable (e.g., temperature), but then relied on imprecise observation to determine the effect of temperature on reaction rates (Figure 7.14). By increasing hard-scaffolding in the e-textbook students received more support in the final problem regarding how to approach the problem and in writing formulae and equations. The result was that the students were able to arrive at a more sophisticated solution that involved measuring, under controlled conditions, the rates of a reaction in various conditions (Figure 7.15).

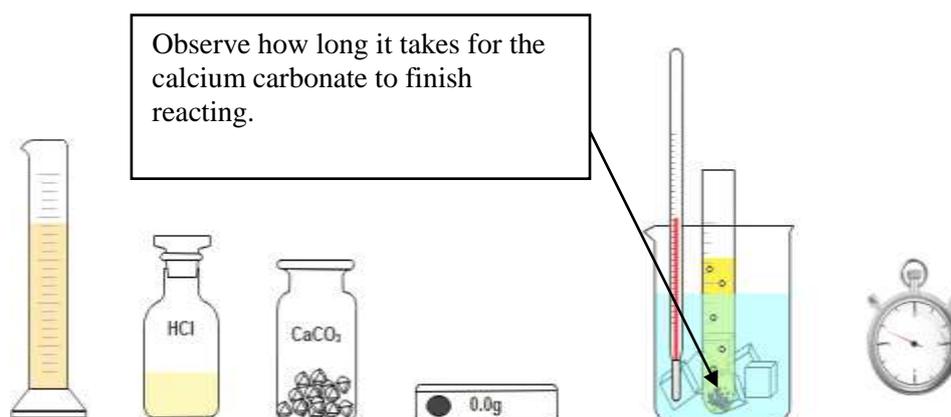


Figure 7.14. Representation of one group's solution to the problem of factors (temperature) that affect the rate of a reaction showing the use of observation in cycle one.

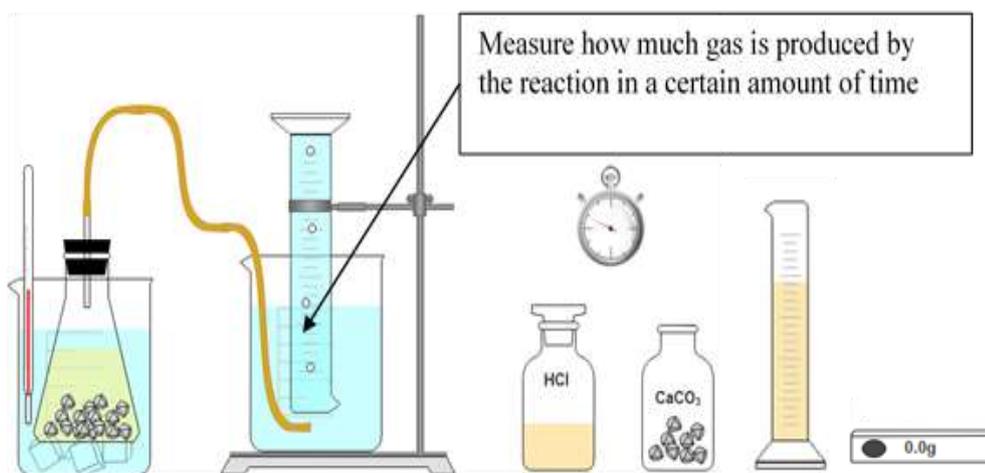


Figure 7.15. Representation of one group's solution to the problem of factors (temperature) that affect the rate of a reaction showing the use of measurement in cycle three.

Groups needed to plan what they will do in a PBL environment so that rather than reacting to the problem to find a solution they are proactive in finding a solution. The students, as a group, work collaboratively in a coordinated way to achieve the goal state. At the same time, students needed to have a strategy for monitoring their progress along the solution pathway. Strategies will vary according to the problem and the students comprising the group.

Students recognised the importance of planning and factors, including allocating resources, background reading, allocating tasks to group members and prioritising learning needs. However, the relative importance students assigned to each, although consistently important in most cases, varied. That students could plan was clear too from observations made during the cycles, although the level of success was dependent on how the group functioned.

Students used a variety of methods to assess their progress through each problem. These methods were variable and dependent on the problem and the groups working on those problems. However, all groups could put forward a functional

strategy that they could use to monitor their progress. Being able to put forward a functional strategy illustrated that it is important not to emphasise a specific strategy to use, which is particular to PBL, but rather ensure that students know a set of possible solutions that they can use effectively.

7.4.3 The impact of the e-textbook intervention on engagement

Student engagement means that the students are productively participating in the problem-solving exercise and working, as part of a group, towards a solution. Factors such as usefulness and the difficulty of the content, the confidence of the students to approach the task, and the enjoyment they gained from the work determined their level of engagement and affected their motivation for working on the problems encountered. In all cycles and iterations, the students considered the problems to be somewhat difficult, and their level of enjoyment varied greatly with an acknowledged preference for different hands-on activities. Students did not see the relevance of the problems they were working on during the iterations. Students found working in a PBL environment challenging, even after completing one set of problems. While the hands-on nature of the topics was a positive factor, external influences such as a student's choice of career path (affecting how they perceive science) did determine their level of enjoyment. E-textbooks can go part of the way to supporting students, especially regarding their confidence, by providing appropriate scaffolding. The support may also help students perceive tasks as challenging rather than unachievable if the e-textbook can, as was the intention of this study, be designed in situ to meet specific needs.

7.5 The Final Road Model for PBL Using E-textbooks: Lessons Learned

E-textbooks provide a useful way of introducing students to PBL and allowing them to develop as independent learners who can work in collaborative teams to achieve not only improvements in knowledge acquisition but also in transfer of problem-solving skills and engagement. In considering the achievement of the goal state at the end of the road, it is useful to review the initial state. In the initial state, many students were the passive receivers of knowledge, who would regurgitate isolated facts in tests and examinations. They were not able to transfer skills from one topic to another, even within the same discipline, and showed little engagement with the subject matter. Figure 7.16 details the students' transition to active learners who could transfer skills between problems and engage with the content they were learning. By changing many constraints into affordances, it was possible to achieve this transition.

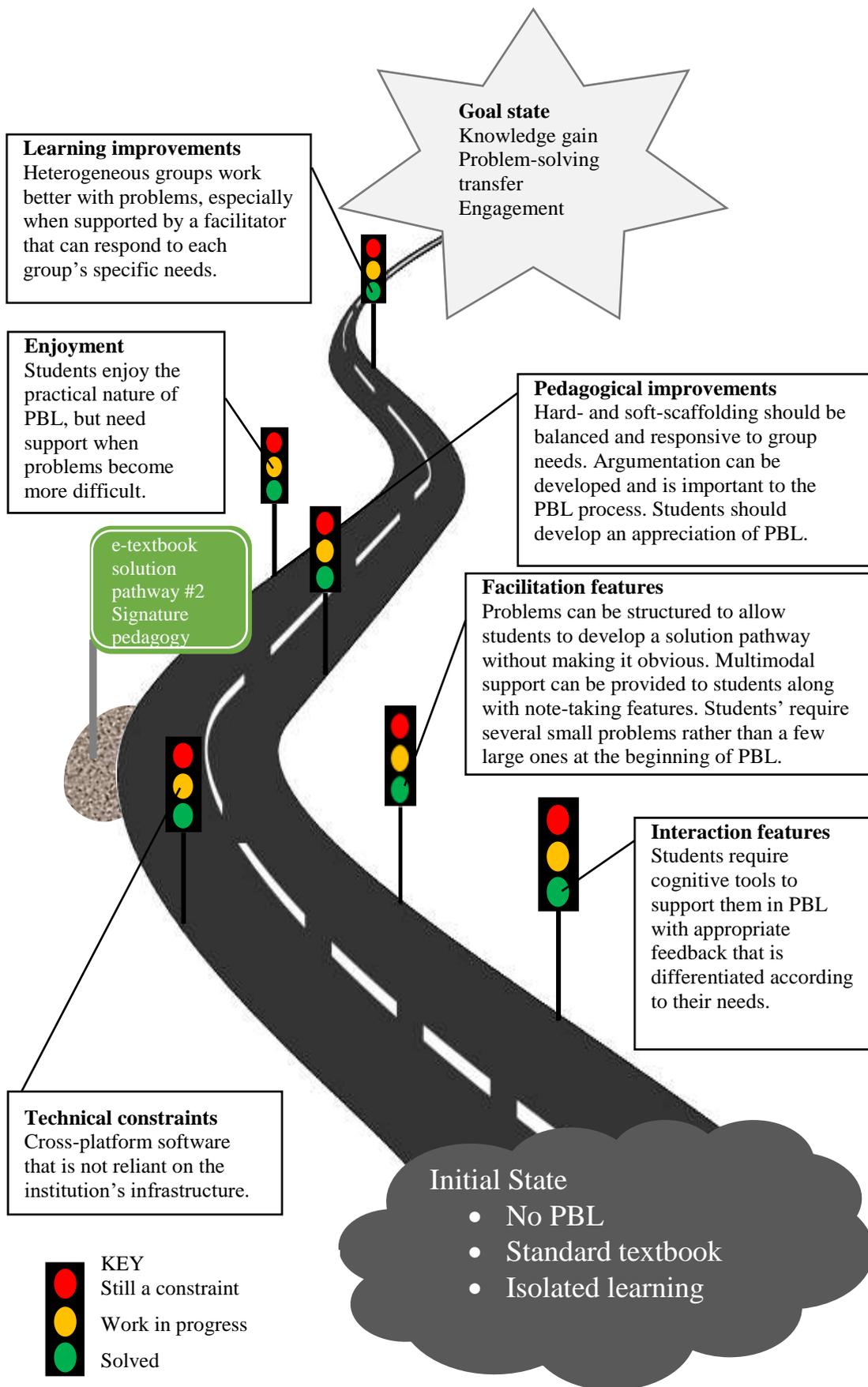


Figure 7.16. The final road model describing the development of the PBL e-textbook.

For PBL to work successfully, students need to be able to interact with several different aspects of the learning environment. Student interaction with each other was initially constraining student learning. By placing students in heterogeneous ability groups not based on friendship, this constraint was ameliorated (as seen in Figure 7.16). In working with such groups, the facilitator needs to be aware of indicators of group dysfunction and provide intervention (soft-scaffolding) as required. Hard-scaffolding can pre-empt some adverse contingencies by upskilling novice students in the fundamentals of working in a PBL group. Such hard-scaffolding can take many forms but should include animation, audio and text. Cheating (e.g., copying) is one aspect of student interaction that should be discouraged, and this can be achieved using problems that are perceived by students to have some form of authentic value to them, be it skill development, knowledge acquisition or another feature. While the problem is pre-eminent in fulfilling this requirement, explaining the purpose of the problem is also necessary as students may not appreciate the underlying objectives that the problem is attempting to achieve.

In using an e-textbook with students, their perceptions of what a textbook should provide constrained their learning. Therefore, it was necessary to develop an e-textbook that facilitated PBL by providing students with cognitive tools when required, accommodating different learning styles, providing targeted feedback and allowing for note-taking. In this way, the e-textbook not only maintains many of the features of the traditional textbooks, but also becomes superior to them while still maintaining the PBL environment for the students.

The problems presented to students require careful attention. The problems need to be structured enough to allow analysis by students to develop a solution

pathway, but not so structured as to provide them with that pathway (as seen in Figure 7.16). Prior knowledge is important, although the level of such knowledge varies with the topic and forming heterogeneous groups ensures a variety of levels within the group. The problem should not be an end in itself, but a means to the end of promoting student learning, which includes the transfer of skills to other problems. In this regard, small, interrelated problems worked better than single large problems.

Throughout this study, the teacher's role as a facilitator changed continuously owing to students requiring different levels and types of support. However, some commonalities of the role existed that are transferable into hard-scaffolds in the e-textbook. These included group-work, researching and engagement. However, other issues were transient or did not readily lend themselves to incorporation in the e-textbook, such as specific personality differences and prolonged absence of students. Thus, while an e-textbook can help alleviate the demands placed on a facilitator by updating the hard-scaffolding, it cannot replace the facilitator completely, and their role remains crucial. Figure 2.3, presented in the Literature Review, described the relationship between the facilitator, the students and technology. The influence of the facilitator was shown to decline along with that of technology with a commensurate rise in student learning (self-regulation and knowledge). That model may have overstated the decline of the facilitator's influence and continued interaction of the facilitator with the groups was required, albeit at a reduced level in some instances.

Linked with learning constraints in PBL are pedagogical constraints that prevent students from achieving the benefits of engaging in PBL. These constraints need to be mitigated to allow students to engage in PBL purposefully. Scaffolding

was shown to be crucial in enabling students to negotiate the PBL environment successfully. Both domain-general and domain-specific scaffolding were required, and it provided feedback to the students. Scaffolding was in two forms, hard and soft, and the balance between the two was determinable based upon student familiarity and group dynamics. However, factors such as student familiarity and group dynamics vary, which means that each situation will, to some extent, be unique and require specific in-situ modification.

Argumentation is another aspect of PBL that requires attention.

Argumentation does not necessarily occur naturally but can develop and evolve within a group and will be aided by effective group dynamics. Therefore, even in situations of group dynamics, the development of argumentation must be supported. Support needs to be in the form of hard and/or soft-scaffolding with the relative amounts of each and its form being variable, depending on the group's experiences and interactions.

When confronted with PBL environments, students can find the change difficult and threatening. They are now responsible for the acquisition of their knowledge rather than simply trying to absorb it. The students need to know how PBL can help them learn new concepts more effectively and develop new skills that they can apply to problems encountered both at school and beyond the classroom. Crucial to this issue is the group's response to the challenges PBL presents to them. A resilient and confident group will be able to work through the problem effectively. A group that does not possess confidence and resilience will require support, before any substantial progress on understanding PBL can be achieved.

Students using laptops with different operating systems can cause issues regarding support for different platforms and accessing networks. Both issues were apparent in this study and no solution was found. Therefore, software must be as cross-platform as possible, and it should not place stress on networks by being machine, rather than server, based. The school technology infrastructure should be fit for purpose. If this is not the case, the PBL process suffers as students become frustrated (Figure 7.16).

Student interaction with the e-textbook occurred in several different ways. The e-textbook assessed the student's understanding of different concepts, providing feedback and specific support when required. In later cycles, the e-textbook had note-taking facilities and a glossary. Specific support tools provided scaffolding in areas where a lack of knowledge could adversely affect students' performance. For example, by including cognitive tools to assist students in writing chemical formulae and balancing chemical equations. Improvement of cognitive tools occurred in each successive cycle during this study informed by feedback and observation of students.

Features that needed to be incorporated into an e-textbook to affect student learning positively became apparent during the study. The design of the problems changed during this study in response to student observations, responses to the problems and feedback. The problems should allow analysis by students so that a solution can be planned in their groups through researching, using prior knowledge and producing testable hypotheses. There needs to be a balance in the structuredness of the problems between providing enough structure to allow students to develop a solution while not making the solution obvious. In designing such problems, many factors require consideration, including, but not exclusively, clarity, relevance and

difficulty. Consideration also needs to be given to how the problem will develop teamwork, self-directed learning and critical reasoning.

In designing the e-textbook, it was important to include multimodal presentations for students that could match their preferred learning style. These presentations include not only the problems themselves, but hard-scaffolding related to basic concepts and PBL skills. Controlling student progress through the e-textbook was beneficial because it prevented them from skipping ahead and missing vital concepts, skills or feedback. Feedback in all areas of PBL was a significant aspect of the e-textbook design. The use of specific feedback that responds to students is an area that needs particular consideration when developing e-textbooks for PBL. Differential feedback in the e-textbook accommodates individual differences.

Enjoyment is an important consideration in designing a PBL environment and is perhaps the most difficult to control. Students enjoyed the practical nature of the problems, which is an important aspect of their design. In some cases, the practical aspect became all-consuming for the students resulting in less skill and knowledge acquisition than was desirable. Problems, where the difficulty level increased, saw student enjoyment decline, and increasing support did not ameliorate this decline. It is necessary to balance the amount of practical work in the problems with their difficulty and the amount of support provided. Ideally, small interconnected problems with hard- and soft-scaffolding were preferred.

Implementation of PBL by individual teachers in their classrooms is possible, but it is not an ideal situation. When an institution implements PBL, it is easier for the students to develop and maintain the skills required and places less stress on them as they do not experience completely different pedagogical

approaches when moving between classes. However, changing the teaching pedagogy of an institution is generally beyond the purview of a classroom teacher, and as such, they can only act as an example of how classrooms could run. In such situations, it is important to remain faithful to the ideals of PBL while ensuring that they are workable in the school environment. To this end, the development of a signature pedagogy (Shulman, 2005) allows for the development of the PBL environment while accommodating the constraints placed on teachers. Shulman (2005) noted each profession has its own signature pedagogy or ways of teaching. Crippen and Archambault (2012, p. 162) defined inquiry-based instruction using technology as signature pedagogy of STEM education. However, this may be an oversimplification because working with technology involves balancing learning through PBL with the demands of timetables, student acceptance of PBL and assessment requirements. Therefore, a more flexible approach may be required, which could involve combining PBL with more traditional teaching methods to cover basic concepts. The balancing of different teaching approaches does not devalue PBL, but rather maximises the time available for its intended purpose of student-centred learning. The development of a signature pedagogy for PBL in secondary school science is essentially the road travelled during the course of this research, hence the Unknown Road in Figure 7.1 became the Signature Pedagogy Road in Figure 7.16.