Implementation of science based on the 5E learning model: Insights from teacher feedback on trial Primary Connections units

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The Australian Academy of Science's *Primary Connections* is a curriculum and professional learning initiative that aims to enhance the status of science at the primary level. Its structure and pedagogy is based on an enhanced 5E learning model. From 2005-2012 numerous teachers have implemented trial *Primary Connections* units and provided detailed written feedback. The feedback included teachers' perceptions of the strengths and weaknesses of each of the 5E phases and many related aspects. This paper reports on insights gleaned from an analysis of more than 3000 comments from over 200 teachers and relates to 16 units across varied content strands and levels of learning. Using various lenses (e.g., purposes of the 5E phases, inquiry, language and assessment) to interpret teachers' perceptions, this analysis has revealed, among a range of outcomes, the impact *Primary Connections* is having on teachers and students, the extent to which aspects of the enhanced 5E learning model are being addressed, and areas which could further strengthen professional learning and the improvement of science pedagogy at the primary level.

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INTRODUCTION

Primary Connections is an innovative national curriculum and professional learning initiative of the Australian Academy of Science. It has several purposes. These include improving the teaching of science in Australian primary schools and enhancing the scientific literacy of primary students. *Primary Connections* also aims to develop a supportive environment for students and teachers to learn and teach science.

The curriculum resources associated with the *Primary Connections* initiative revolve around a research-based model, which guides the sequencing of students' learning experiences. This model is the 5E learning cycle (Bybee, 1997). It has five consecutive phases (Engage, Explore, Explain, Elaborate and Evaluate) each with its own specific purposes. An enhanced form of the cycle is used in *Primary Connections,* which has incorporated strong literacy links and embeds assessment within the model.

Primary Connections may be considered a science education reform initiative that is encouraging teachers to embrace constructivist and inquiry-oriented pedagogies. In *Primary Connections,* there is a balance between personal and social constructivist emphases and teacher and learner roles reflect this duality. The inquiry-oriented pedagogy and embedded assessment influence other teacher and learner actions. Expectations of what learners and teachers would be talking about and doing in *Primary Connections* classrooms, in part, underpin this research.

Nature of this research

The aim of this research was to enhance knowledge of how teachers understand and implement *Primary Connections*; in particular, the 5E learning cycle. It is based on feedback from teachers who have trialled *Primary Connections* units. Many of these teachers submitted extensive written feedback on the strengths and weaknesses of the overall sequence of a 5E unit and the activities in the lessons within each phase of the 5E learning model. They also provided comments about the strengths and weaknesses of other aspects of these units, such as their implementation of 'how to' strategies and scaffolds. For example, how to use the 'word wall' and the 'investigation planner'.

This paper outlines how teacher feedback from implementing *Primary Connections* trial units (over an extended period) has been analysed in order to provide insights about the effective teaching and learning of primary science. One facet of analysing the teachers' feedback was to see if it reflects an understanding of the embedded 5E model and what it means to implement it. Also, when teachers reflect on their implementation of *Primary Connections* units, the strengths and weaknesses they identify will also illuminate some of their beliefs about science, science teaching and science learning.

Research questions

The broad aims of this research are encapsulated in the following general research questions:

- What understandings and insights about learning and teaching of science are embedded in teacher feedback about the implementation of *Primary Connections* trial units?
- What are the implications for the development of curriculum support materials and teachers' professional learning, from these insights?

Specific research questions

In what ways does teacher feedback about the implementation of trial *Primary Connections* units infer:

I. teachers' understanding, and practice, of the 5E learning cycle and associated constructivist and inquiry-oriented pedagogies (e.g., purposes; teacher and student roles)?
II. if characteristics and conditions for effective science practice were present (e.g., reference to meaningful conceptual learning, interest and engagement of students; development of science inquiry skills; appropriate use of ICT)?

III. whether other factors (e.g., teachers' beliefs) emerged from the data that were enabling (or obstructing) effective constructivist and inquiry-oriented science practice?

In this paper, results will be overviewed. Full details of this research project may be found in *Teaching primary science: Trial-teacher feedback on the implementation of Primary Connections and the 5E model* (AAS, 2012).

BACKGROUND LITERATURE

This study was set within the parameters of the aims, purposes and underlying rationale of the *Primary Connections* project, especially its intended implementation of an enhanced 5E learning cycle, as well as the research and professional literature that has identified attributes of effective primary science practice. In responding to the above research questions, analysis and interpretation of teacher feedback from trial *Primary Connections* units was guided by this literature.

The pedagogical principles relevant to this research are those that underpin *Primary Connections*. These include its use of the 5E learning cycle as a constructivist learning model to plan and implement science at the primary level. This pedagogical model has been enhanced by *Primary Connections* to incorporate strong connections between science and literacy, an emphasis on inquiry-oriented science with investigating scientifically as a focus, assessment that is embedded across the 5E phases, as well as cooperative learning (AAS, 2008). The 5E learning cycle and its embedded enhancements were the focus when the teacher feedback data were analysed.

The literature review identified major research findings relevant to the above research questions. It focussed on the following four main areas; for each area a very brief overview of the relevant literature is provided.

The 5E learning cycle, and personal and socio-constructivist emphases within it

The 5E learning cycle, with its Engage, Explore, Explain, Elaborate and Evaluate phases, is a constructivist model for planning and implementing science. *Primary Connections* has described the purposes of each phase (see Appendix 1) (AAS, 2008). This model embraces personal and social constructivist learning emphases (Yore, Anderson & Shymansky, 2005). Investigating scientifically, with an emphasis on science inquiry skills, is embedded in the cycle, as are diagnostic, formative and summative assessment practices.

The 5E cycle has been referred to as a different pedagogical 'paradigm' (Cavallo & Laubach, 2001, p.1035). For teachers who have taught primary science using traditional transmission approaches, as well as those who have used hands-on tasks, perhaps with an emphasis on some science processes, such as observing, but not, for example, with the intention of students constructing key conceptual understandings, then implementing the 5E cycle would be a pedagogical shift. This is because it requires teacher and student roles that contrast with those found in more conventional science teaching and learning. Harlen (2009) has identified these roles in her conceptualisation of a pedagogy, which she argues will achieve scientific literacy outcomes for learners. Her pedagogy draws on four different perspectives that have emerged from research about effective science learning (see Appendix 2). These are a (personal and socio-cultural) constructivist perspective, a 'discussion, dialogue and argumentation' perspective, an inquiry perspective and a 'formative use of assessment' perspective. The resultant list of learner and teacher roles comprehensively covers most expectations of learners and teachers in the *Primary Connections* enhanced 5E model.

Teachers' understanding and implementation of the learning cycle

This project is, in part, seeking evidence as to whether teachers are implementing the 5E model as it was intended. This would be dependent on how well teachers understood the purposes of the 5E learning cycle. It may not be assumed that relatively brief professional development about the learning cycle will necessarily lead to understanding. Many preservice teachers (n=55) who had received instruction and read and critiqued research about the learning cycle, engaged in group and class discussion about it, participated in model 5E lessons, as well as developed lesson plans based on the model and taught a lesson using the 5Es, still had a limited understanding of the model (Hampton, Odum & Settlage, 1996). Clearly they found it difficult to understand. They held a range of misconceptions about it.

Various studies (reported in Cavallo & Laubach, 2001) determined that teachers vary in their understanding of the learning cycle from a "sound understanding to misunderstanding" (p.1036). Teachers' behaviours varied in each of the phases depending upon their understanding of the model. In a more recent review of research on the impact of the learning cycle Marek (2009, pp.147-48) unequivocally states that teachers "must understand the learning cycle's theoretical underpinnings" to successfully implement it with their students. "Teaching behaviours were found to follow distinguishable patterns depending upon teachers' understanding of the learning cycle and theory base". Marek then provides examples of various patterns of behaviour if teachers had a limited understanding of the cycle. These patterns, on the basis of related research, would result in less effective learning in science. Some of the reviewed findings from earlier benchmark studies found that learning was less effective if a phase was omitted and/or the phases were taught out of sequence. Furthermore, the Explain phase was important to "optimum learning" and

> … explaining a concept before providing experience with materials results in little or no conceptual understanding… exploration, which produces data, needs to be followed by discussions (as in the Explain phase)
> (Abraham & Renner, 1985; Renner, Abraham & Howard Birnie, 1988 cited in Marek, 2009, p.144)

Others have reported that students in classes where the learning cycle model was being implemented were more highly motivated, more curious to learn about specific topics and had an overall increased excitement about learning (see, e.g., Barman in Marek, 2009; Cavallo & Laubach, 2001).

The characterisation and components of effective learning of science

In a comprehensive and large-scale study of the implementation of science in Victorian primary schools, the Science in Schools (SiS) project identified eight components that effectively support student learning and engagement in science. These components were one of the lenses through which the teachers' feedback comments were analysed. They are:

1. Students are encouraged to actively engage with ideas and evidence.
2. Students are challenged to develop meaningful understandings.
3. Science is linked with students' lives and interests.
4. Students' individual learning needs and preferences are catered for.
5. Assessment is embedded within the science learning strategy.
6. The nature of science is represented in its different aspects.
7. The classroom is linked with the broader community.
8. Learning technologies are exploited for their learning potentialities.

(Extracted from Tytler, 2003, p. 285)

The 'purposes' of the constructivist-based 5E learning cycle (AAS, 2008) may be positioned within this more encompassing framework. Most of the SiS components are evident within the cycle. Components (1) and (2) are integral to the 5E phases. Developing meaningful science understandings is a core outcome of the learning cycle, and occurs primarily through students actively engaging (physically and mentally) with ideas and evidence. This active engagement incorporates students' use of general skills (e.g., literacy skills such as listening, reading and writing) as well as science inquiry skills such as observing, predicting and testing ideas. *Primary Connections* encourages teachers to use an inquiry-oriented approach by embedding an aspect of the Nature of Science (NoS), namely investigating scientifically, in the cycle (see SiS component [6]). The initial phase of the 5E cycle especially aims to engage students' interests as in SiS component (3), while assessment is embedded in all phases, which is SiS component (5). By using an SiS lens, learning technologies and links to the wider community were not overlooked.

Factors influencing teachers' willingness to change pedagogical practices

As *Primary Connections* may be considered a reform in primary science education, then the literature related to implementation of 'reform pedagogy' was relevant to this study. Several findings assisted in the analyses and interpretations of the teachers' feedback. These included:

- Teachers can experience negative reactions towards new pedagogies in early periods of implementation, but if the professional learning period exceeds between 40 and 80 hours then positive effects emerge (Supovitz and Turner, 2000). Furthermore, periods of a year or more have been reported for teachers to change their teaching philosophy and approach towards a learning cycle mode (Barman in Marek, 2009). *Primary Connections* teachers who have trialled one or more units would be approaching some of these milestones.

- Several studies have reported readily identified factors that may influence implementation of new pedagogies. These have included teachers' perceptions that sophisticated equipment is required and equipment is difficult to access, administrative support is lacking, school climate is not conducive to change, many science concepts are too abstract and difficult to understand by primary students, science is not relevant to students' lives, and there simply is not enough time to teach science (Carlone, Haun-Frank & Kimmel, 2010 and numerous references therein; Levitt, 2001; Smith & Southerland, 2007). Other issues have also emerged, such as believing that inquiry strategies would not assist student learning, and also that it would be difficult to oversee authentic science investigations (Sahin, Isiksal & Ertepinar, 2010; Smith & Southerland, 2007), and finding that there were difficulties with other staff (Carlone, Haun-Frank & Kimmel, 2010; Marbach-Ad & McGinnis, 2008).
- Teacher beliefs, which are among the above factors, are thought by many researchers to be a pivotal consideration when seeking change in pedagogical practices. Levitt (2001), Marbach-Ad & McGinnis (2008) and Smith & Southerland (2007), in reviewing numerous studies, concluded that there is substantive evidence that teachers' beliefs about science, teaching science and learning science directly influence their classroom decisions and actions about teaching science.

> Theory holds that people tend to act according to their beliefs. More accurately then, as Haney et al. (2002) suggested, the beliefs that teachers hold regarding science reform ideas are truly at the core of educational change (Marbach-Ad & McGinnis 2008, p162).
>
> In some cases, teachers' conceptions of specific subject matter and content instruction are completely incongruous with those of policy makers or reformers (Smith & Southerland, 2007, p.399).

Teacher beliefs, therefore, can be an impediment or a catalyst for science education reform[1].

Several studies have reported how teachers' beliefs are influenced by their context. This can be their designed (e.g., buildings), human (e.g., students) and sociocultural (e.g., policy) environment. Depending upon how teachers engage with their context, this can partially determine how effectively they function as teachers of primary science (Lumpe, Haney & Czerniak, 2000). These authors reported that teachers' beliefs indicated that class size, planning time, classroom environment, science equipment and funding had the largest gaps between enabling and likelihood scores[2].

In an insightful study, Carlone, Haun-Frank & Kimmel (2010) report that reformist science teachers saw themselves as 'becoming' science teachers, rather than statically labeling themselves as science or non-science persons or teachers. This suggests that if teachers of primary science perceived themselves as 'becoming' rather than 'static' then beliefs need not be an irresistible barrier to pedagogical change. This study also found that a 'critical resource' in encouraging teachers to persist in teaching constructivist and inquiry-oriented science was *to keep trying to teach in these ways*. This helped these teachers to see 'becoming science teachers' as a life-long professional process (Carlone, Haun-Frank & Kimmel, pp. 956, 961). This finding is consistent with considerable evidence (see Levitt, 2001) that indicates teachers' beliefs and actions can interact with each other and that changes in one can result in changes in the other. Using this interpretation, Smith & Southerland (2007) contrasted two teachers' beliefs and decisions. They concluded that practitioners modify reforms (like *Primary Connections*) in a range of ways, including ignoring them. Their own identities and beliefs interacted with reforms, such as calls for constructivist and inquiry-oriented teaching, and policies like externally imposed testing. In Smith & Southerland's (2007) study, the teachers "ultimately (chose) to remain true to their personal theories of appropriate practice, both despite and because of the external pressures imposed by the tools of reform" (p.417).

How teachers interact with recommended changes in science pedagogy directly relates to the implementation of *Primary Connections*. This initiative hopes teachers will appreciate the learning model that underpins it (the enhanced 5E cycle). Most teachers who have trialled *Primary Connections* units

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[1] An interesting aside from these studies that can complicate the interpretation of teachers' comments about their pedagogy and/or their implementation of curriculum changes is that they rarely use the pedagogical terminology of science education policy documents or curriculum initiatives such as *Primary Connections*. In an extensive number of interviews with teachers, for example, Levitt (2001) reported that no teachers referred to 'inquiry' in their interview responses about their primary science pedagogy.

[2] These 'scores' were on an instrument these authors used.

have encountered professional development about the initiative, its learning model and associated strategies. The extent to which they have experienced

> scaffolded opportunities over time, with other teachers who are focusing on the same issues, and with the specific content they are teaching… (and have) directly wrestle(d) with the messages of (*Primary Connections* material) and (have) work(ed) through the implications of the (*Primary Connections* aims, purposes and pedagogy) for their own teaching practices (Smith & Southerland, p. 417, parentheses added)

will probably influence how much their teaching practice aligns with the teaching and learning intentions of *Primary Connections*. The additional task of implementing trial *Primary Connections* units and then being encouraged to provide scafolded feedback about lessons labelled with each of the five phases of the learning cycle model, may have been influential for some. Even so, it needs to be borne in mind that Smith & Southerland concluded:

> It is important to recognize that teachers *tend to* perceive (curriculum initiatives and resources) only in terms of content (and activities); they do *not* look to these (initiatives and resources) for description of how that content should be taught. (p. 418, parentheses and emphases added).

Other studies

The full report also refers to several other key ideas associated with reform pedagogy. These included the impact of global Discourses, where Discourses are "taken for granted practices and meanings" that "authorise or sanction allowable practices and meanings" (Carlone, Haun-Frank & Kimmel, 2010, p944) on teachers' beliefs and action. These authors identified a group of teachers they called 'tempered radicals'; these were teachers who made decisions and took actions in their science teaching for reasons that would differ from teachers who did not see primary science teaching as a moral imperative. They, for example, saw integration of science with other subjects in a different light.

In Fittell's (2010a, b) case studies of two Queensland mid-career male primary teachers who had experienced workshops associated with the *Primary Connections* professional learning resource, he reported how over time these teachers started to appreciate that less 'teacher talk' and direction (than their usual practice) allowed students to be more autonomous in their learning. Additional opportunities were provided, after scaffolding, for more open-ended activities (e.g., to explore the pushing and pulling aspects of a toy) and for students to try out ideas and to share their thoughts between themselves. Independent and group investigations became more common. The teachers linked these pedagogical changes to increased student engagement and enjoyment, and improved learning outcomes. Their beliefs about how students learn science changed because they witnessed these changes.

RESEARCH METHODS

The overall approach used in this project was mainly a qualitative content analysis of the comments that teachers made in their feedback about their trialling of *Primary Connections* units. Here, 'meaning' was derived from what is explicit in the words used or "what can be implied from their use from the range of alternatives that may have been employed" (Miller & Brewer, 2003, p.43). Where feasible, and appropriate, frequency counts or estimates of frequency related to various 'meanings' were determined. The researcher used a knowledge of the *Primary Connections* project and its units and related research to 'read into' the teachers' responses and likely interpretations of what teachers may be suggesting about their understanding and implementation of various pedagogies which are the focus of this project[3].

The sample was predetermined by the availability of written teacher feedback about the implementation of trial *Primary Connections* units. This feedback was provided to the *Primary Connections* team over the last six years (2005-2012). A selection of teacher feedback from sixteen units was selected. Four units were selected from each of the four conceptual strands of 'Life and Living', 'Energy and change', 'Natural and processed materials' and 'Earth and beyond'. Within each strand a unit was selected from each stage (Early Stage 1 [ES1], Stage 1 [S1], Stage 2 [S2] and stage 3 [S3]) and where possible units that were linked, for example, *On the Move* ES1 and *Smooth Moves* S1.

[3] In this sense this project is qualitative interpretive research in that the researcher is making a personal assessment of what the teachers' comments are suggesting (Cresswell, 2008).

Documents were the main (qualitative and unobtrusive) data source. These were the detailed written teacher feedback notes (based on a supplied pro-forma) from the implementation of numerous *Primary Connections* trial units. Further input from selected teachers was obtained from a two-tier multiple-choice test that determined teachers' understanding of the purposes of the Explore, Explain and Elaborate phases of the 5E learning cycle (adapted from Odum & Settlage, 1996). Approximately 60 tests were distributed by email and 11 returned (response rate about 20 percent).

The teachers' feedback responses for each of the sixteen units comprised approximately 10-20 pages of typed notes. This feedback documented teachers' views about the strengths and weaknesses of the overall unit, each of the lessons in the various 5E phases, its various components (e.g., resource sheets, word walls, investigation planners), together with any other comments about future implementation of the units. Individual teacher feedback about any one of these areas ranged from a few words to many sentences. Each unit had feedback on between 5 and 11 lessons (mean 7.6 lessons). This equated with the analysis of an estimated number of responses (for the 16 units) of between 2500-3000.

The teacher feedback data were manually analysed. This process enabled the researcher to have a hands-on feel for the data and close inspection of it to ensure that nuances within the teachers' responses were not overlooked. Both deductive and inductive analytical processes were used. The deductive analyses used three checklists. These were the purposes of each phase of the 5Es as described by *Primary Connections* (AAS, 2008); the Science in Schools (SiS) components, which were found to support the effective learning of science (Tytler, 2003), and Harlen's (2009) descriptors of learner and teacher roles associated with science teaching from a constructivist, language/talk, inquiry and formative assessment perspective (see earlier and appendices). If teacher feedback comments explicitly referred to items on these checklists, they were coded accordingly; where appropriate, it was noted if other teacher comments implied the presence of these checklist items. Teacher comments that appeared to disconfirm the purposes, components or roles in these checklists were also coded. Frequency counts were made of the comments associated with the 5E purposes while 'estimates of probability/ possibility' were determined for the components and roles on the other two checklists.

If when reading the teachers' comments using the above deductive coding, other teacher remarks suggested emerging issues of interest related to the research questions, then they were categorised under a range of headings depending on the content of the teachers' comments as in inductive analysis of qualitative data (Cresswell, 2008). As the data were analysed if particular teachers' responses suggested an exemplary or an explicit disconfirming instance of addressing the purposes, components and roles then they were highlighted. 'Track change comments' were used to code all relevant teacher comments, and hence isolate feedback segments that related to a deductive code or an inductive issue or category – this process addressed the confirmability of the findings, as an audit trail could be followed.

As each unit's analysis was completed, an interpretive report was prepared that drew inferences as to if, how, and to what extent the purposes, conditions and roles had been identified[4]. Any emerging issues were listed separately. This process meant that the feedback comments were read on more than one occasion, and at times searched for particular terms/ideas. Extracts from the teachers' comments were added to support the naming of emerging categories. Relevant findings from the literature were integrated into the analyses.

This study has various limitations. Teacher feedback sought perceptions of the strengths and weaknesses of the *Primary Connections* units and its various components as a consequence of implementing them. The feedback varies in its detail and is incomplete in that teachers decided how much detail to include and no further guidance was provided as to what they could include. Furthermore, although supporting extracts from the teachers' comments were related to particular inferences about teachers' understanding and practice of the 5E learning cycle, and associated constructivist and inquiry-oriented pedagogies, teachers were not directly asked to comment on these features. This needs to be kept in mind when reading the inferences from the data.

Also, this report is based on teacher perceptions and self-reports of what happened in their classrooms. In that sense, it will be influenced by teachers' existing beliefs about science and how it is taught, as well as related matters. Teachers volunteered to provide feedback as a condition of receiving *Primary Connections* resources.

[4] Yore, Anderson & Shymansky's (2005, p.86) note of caution in gathering evidence about reform efforts were borne in mind as assertions were made; this is that "many reforms are simply unrealistic in their expectations, looking for immediate gains in student achievement". The literature review draws attention to related issues.

Motivations will have varied among these volunteers, and hence this would impact on the nature and quantity of feedback.

FINDINGS

Detailed findings are described in the full report. The various chapters refer to:
(1) general implementation of the 5E model;
(2) implementation of the *purposes* of each of the 5E phases;
(3) the constructivist, inquiry, language and assessment foci in *Primary Connections* (mainly following Harlen, 2009);
(4) evidence as to whether the SiS components for effective learning of science (Tytler, 2003) were present; and
(5) other implementation issues that arose from analyses of the teachers' feedback. A summary of the key findings for each of these five areas is included with additional detail for (1), (2) and (5); all findings are supported by extracts from teacher feedback (in the full report)- for (1), (2) and, to some extent (5), some standout extracts are integrated in the following outline.

(1) General implementation of the 5E model

- In response to the general strengths and weaknesses of units, by far the most reported response was that they captured both the teachers' (n=47 [responses]; 45% [of responses]) and the students' (46; 44%) interest. The positive impact on student learning (n=20; 20%) and that teachers and students appreciated the presence of investigations (involving fair testing) and interesting observations (both n=11; 10%) were the only other responses mentioned by at least ten percent of teachers. Relatively fewer teachers identified weaknesses. Two related limitations were reported by ten or more percent of teachers, namely that the length of the units (n=22; 29%) and specific lessons (n=10; 13%) were too long and/or had too much content. These data suggest that the overall content, sequence and selection of activities have engaged both teachers and students. Furthermore, although not directly asked, uppermost in several teachers' minds was the positive impact on student learning and the emphasis on an investigative approach.
- Positive teacher feedback about the 5E model included: the positive impact of the model on teachers (its structure, method, encouragement of learner autonomy); the adoption of the model as a basis for their own unit planning and an appreciation that for science lessons to be effective, being hands-on and 'fun' is not enough; indications that teachers' science pedagogies were changing; acknowledgement of the value of focussing on one key science concept or understanding over a range of lessons (but there were viewpoints to the contrary); reporting of student growth in the use of Science Inquiry Skills (SISs); and observed positive impact of teaching consecutive *Primary Connections* focussing on related concepts (e.g., force) or any two units on SIS (e.g., fair testing).
- Problematic feedback about the 5E model indicated that some teachers omitted one or more of the phases, including the 'Explain' and 'Evaluate' phases (for a range of reasons); other teachers may have inappropriately implemented lessons within a phase (e.g., not using the TWLH chart because students did not 'know' anything about solids, liquids and gases in an Engage phase).

  This 'problematic feedback' could be related to some teachers having a limited understanding of the overall purpose of some 5E phases. A two-tier test of teachers' understanding of the purposes of the Explore, Explain and Elaborate phases of the learning cycle (Odom & Settlage, 1996) found that three (of 11) teachers selected correct responses for 90 percent of the 13 questions (irrespective of reasons) while three teachers selected correct responses (and reasons) for 70 percent of the items. This suggests that many teachers may have a limited understanding of these phases. In this very small sample, the Explore phase is better understood than the Explain or Elaborate phases.

Two issues raised by these responses were, firstly, the tension between following teachers' perceptions of student interest and focussing on a central concept or understanding, with teachers offering contrasting viewpoints and, secondly, the regular references to lack of time. As one teacher expressed it: "Giving students enough time to complete tasks; think about responses but not waste time was always on my mind" (*Change detectives* S3 T9G). Effective learning in science does require time for students to reflect on what they are doing. Of interest was that teacher estimates of time to complete a unit (from 21 teachers across five units) indicated that units take on average seven to ten hours to complete.

(2) Implementation of the purposes of the 5E phases

Tables 1 and 2 provide an overview of the minimal levels of response to each of the 5E phases across the four content strands and the four primary levels. These levels are minimal because more teachers may have addressed these purposes but not mentioned them. The levels are indicative of the responses across the majority of units within a strand. If two or more units had 75% or more responses that referred to a particular phase's purpose, then the addressing of this purpose was rated 'very high'; 50%; was 'high'; 25% 'moderate'; and otherwise 'low'. The sample sizes varied from 8 (*Staying alive*) to 18 (*Marvellous micro-organisms*), while the range of frequency of responses (for each phase) varied from 0 (in 7 units for 'raise questions for inquiry') to 9/9 (for 'create interest and stimulate curiosity' in *Change detectives*). In summary, the detailed analyses of the 5E purposes indicate that:

- Some purposes in each phase are addressed very well across all strands and primary levels (e.g., creating interest in the Engage phase; providing experience of the phenomenon or concept in the Explore phase, using conceptual tools in the Explain phase, using a variety of modes in the elaborate phase and students reviewing their understanding in the Evaluate phase); and
- Some purposes may not be addressed by many teachers across all strands and primary levels (e.g., raising questions for inquiry in the Engage phase; students comparing their own explanations in the explain phase).

Otherwise there are mixed findings, with several purposes in the moderate to high range across strands and year levels.

There do not appear to be any consistent trends across strands and year ranges. A *very* speculative look at the tables might suggest that:

- 'Life and living' units tended to address engage purposes more than other strands;
- 'Life and living' and "Energy and change' units tended to address explore, elaborate and evaluate purposes more than other strands;
- 'Natural and processed materials' and 'Earth and beyond' tended to address Explain purposes more than other strands; and
- Upper primary students (S3) tended to address Explore and Evaluate purposes more than other levels.

As stated these are proffered more for reflection than in any sense being definitive (due to the nature of the data and the analyses). If they resonate with *Primary Connections* teachers then there may be reason to reflect further on the strands and levels.

The following describes in more detail some of the findings related to the purposes of each 5E phase.

Table 1: Minimum levels of responses[5] that explicitly addressed the purposes of the 5E phases across four units in each of the four content strands

Purpose	Life and living	Energy and change	Natural and processed materials	Earth and beyond
Engage phase				
Create interest and stimulate curiosity.	Very high	Very high	Very high	High
Set learning within a meaningful context.	High	Low	Low	Low
Raise questions for inquiry.	Low	Low	Low	Low
Reveal students' ideas and beliefs, compare students' ideas	High	Moderate	Moderate	Moderate
Explore phase				
Provide experience of the phenomenon or concept.	Very high	Very high	Very high	Very high
Explore and inquire into students' questions and test their ideas.	Moderate	Moderate	Low	Low
Investigate and solve problems	High	High	Moderate	Moderate
Explain phase				
Introduce conceptual tools that can be used to interpret the evidence and construct explanations of the phenomenon.	Very high	High	High	High
Construct multi-modal explanations and justify claims in terms of the evidence gathered.	Moderate	Low	High	High
Compare explanations generated by different students/groups	Low	Low	Moderate	Low
Consider current scientific explanations	Moderate	High	Moderate	Moderate
Elaborate				
Use and apply concepts and explanations in new contexts to test their general applicability	Moderate	Moderate	Moderate	Low
Reconstruct and extend explanations and understanding using and integrating different modes, such as written language, diagrammatic and graphic modes, and mathematics	Very high	High	Moderate	High
Evaluate				
Provide an opportunity for students to review and reflect on their own learning and new understanding and skills.	Very high	High	High	Very high
Provide evidence for changes to students' understanding, beliefs and skills.	Very high	Moderate	Moderate	Low

[5] These levels are minimum levels as more teachers may have addressed these purposes but not mentioned them. The levels are indicative of the responses across four units at the same primary school level/stage. If two or more units at a particular level/stage had 75% or more responses for a particular purpose then addressing that purpose was rated very high; 50% high; 25% moderate and otherwise low. The sample sizes varied from 8 (*Staying alive*) to 18 (*Marvellous micro-organisms*), while the range of frequency of responses varied from zero (in 7 units for raise questions for inquiry) to 9/9 (for *Change detectives*).

Table 2: Minimum levels of responses[6] that explicitly addressed the purposes of the 5E phases across four units in each of four levels of primary schooling

Engage phase	Early stage 1	Stage 1	Stage 2	Stage 3
Create interest and stimulate curiosity.	High	Very High	Very high	Very high
Set learning within a meaningful context.	Low	Low	Low	Low
Raise questions for inquiry.	Low	Low	Low	Low
Reveal students' ideas and beliefs, compare students' ideas	Moderate	Moderate	High	Moderate
Explore phase				
Provide experience of the phenomenon or concept.	Very High	Very High	Very High	Very High
Explore and inquire into students' questions and test their ideas.	Moderate	Moderate	Moderate	Moderate
Investigate and solve problems	Moderate	High	Moderate	Very High
Explain phase				
Introduce conceptual tools that can be used to interpret the evidence and construct explanations of the phenomenon.	High	High	High	Very High
Construct multi-modal explanations and justify claims in terms of the evidence gathered.	High	Moderate	High	High
Compare explanations generated by different students/groups	Low	Low	Low	Low
Consider current scientific explanations	Moderate	High	High	Moderate
Elaborate				
Use and apply concepts and explanations in new contexts to test their general applicability	High	Moderate	Low	Moderate
Reconstruct and extend explanations and understanding using and integrating different modes, such as written language, diagrammatic and graphic modes, and mathematics	High	Very High	High	High
Evaluate				
Provide an opportunity for students to review and reflect on their own learning and new understanding and skills.	Very High	High	Very High	Very High
Provide evidence for changes to students' understanding, beliefs and skills.	Moderate	Low	Moderate	High

[6] These levels are minimum levels as more teachers may have addressed these purposes but not mentioned them. The levels are indicative of the responses across four units at the same primary school level/stage. If two or more units at a particular level/stage had 75% or more responses for a particular purpose then addressing that purpose was rated very high; 50%; high; 25% moderate and otherwise low. The sample sizes varied from 8 (*Staying alive* ES1) to 18 (*Marvellous micro-organisms* S3), while the range of frequency of responses varied from zero (in 7 units for raise questions for inquiry) to 9/9 (for Create interest and stimulate curiosity in *Change detectives* S3).

Engage phase

Most units created interest and stimulated curiosity, with many identifying students' ideas and/or having students compare their ideas. Most teachers did not indicate that student questions were raised for inquiry. Although many teachers did not directly refer to 'setting learning within a meaningful context', the *Primary Connections* units generally suggested a 'meaningful context'; however, on occasions a few teachers did comment to the contrary.

Some insights from this phase, for each of the four purposes, included:

- Create interest and stimulate curiosity
  - Interest was created by the nature of the Engage task; the strategies used; the inclusion of a novel aspect; direct involvement of many students' personal interests; a suggested technique and the content area.
  - The interest of the students sometimes surprised the teachers (e.g., *Water works*; *Smooth moves*).
  - Teachers can differ markedly in their reports of student interest in a unit; *Smooth moves* was an example.
  - Teachers held contrasting views about the role of discussion and its use, instead of having further hands-on tasks
- Set learning within a meaningful context
  - Many teachers did not refer to explicit actions (e.g., make verbal connections with every day life; bring in an aid such as a toy) to create a meaningful context
  - Many *Primary Connections* units included implicit 'meaningful contexts' (e.g., links to home and family); some teachers thought some units lacked this aspect (e.g., *Push-pull*). This was surprising at times, for example, *Material matters* (about solids, liquids and gases).
- Raise questions for inquiry
  - Rarely mentioned by teachers, but some used a variety of strategies and techniques," The kids loved writing questions to add to the wall" (3G *Electric circuits*); "Students enjoyed this concept/means of displaying ideas and used sticky notes for questions, ideas and findings" (1G re Word wall) *Electric circuits*); "used 'Thinking strategies' (namely) 'I see; I think; I wonder'…" (T18 *Electric circuits*). Findings suggest that this is not a common practice; it is possible teachers may be unsure how to handle students' questions in science.
- Reveal students' ideas and beliefs, compare students' ideas
  - In general more than a third of teachers made reference to this purpose, but this was mainly to 'revealing students ideas and beliefs'. A wide range of elicitation approaches were mentioned; these were TWLH charts or similar methods such as "sticky notes for questions, ideas and findings" (*Electric circuits* T17G); the 'Global Analytical Super Sheet' [T5G *Marvellous micro-organisms*], 'Jot Notes' [T18G *Marvellous micro-organisms*] or 'Jot Thoughts' ("a Dr Spencer Kagan strategy") [T16G *Marvellous micro-organisms*]); mind-maps [T2, T3 *Spinning in space*] including using *kidspire/ kidspiration* (T12 *Spinning in space*; T5 *Material matters*); brainstorming; "partner discussion" (T3 PA) as well as class discussion, sometimes catalysed with hands-on tasks; "a scientists' chat board where 'junior scientific investigators' pinned notes about their latest … questions" (19G *Electric circuits*); drawing; a literacy writing task; a "pre-concept survey" (T17 *Electric circuits*); a concept cartoon; and provided resource sheets.
  - Some teachers had difficulties with revealing students' ideas; for example, Engage tasks too difficult; lack of appropriate vocabulary; and non-familiarity with mind-maps. Others expressed anxiety about recording students' ideas that were not 'scientific': *I fear the children will learn the incorrect thought as they are accepted and put on the wall. Upon reflection I feel I should not put the very incorrect answers up.* (T5 *Smooth moves* Eng, italics added)
  - Several teachers made comments indicating their appreciation of the value of elicitation, although only two referred to it as 'diagnostic assessment'. Two comments that exemplified this aspect were:

> Good activity to uncover misconceptions. Students wanted to know correct answer! Interesting to see how thoughts differed. Important to allow students at this stage to have their own thoughts and not be influenced by others. (T3 *Earths place in space* S3)
>
> Lesson 1 was a real "eye opener." All students thought they knew it all. However, many misconceptions were identified, which were able to be recognised and amended by the students during the course of the unit. Cutaway diagram of earth was a good example as all

> are familiar with cutaway earth diagram. A useful assessment of developing concepts was to amend the original drawings in a different colour or highlight changes. Each amendment was dated. (19 *Electric circuits* Eng)

However, a few teachers' comments suggested a misunderstanding of this purpose, for example, listing as weaknesses of the Engage lessons "Misconceptions of day and night initially" (T16 *Spinning in space* S2) and "Showed a surprising lack of knowledge or ideas" (T12 *Spinning in space* S2).

- Very few teachers referred to students sharing their ideas. Examples like the following were very rare: in *Push-pull*, the children "were very keen to share what they already knew about pushes and pulls" (T6) and "enjoyed the experiment, however had many arguments about whether blowing the ball was direct contact or not" (T5).

Explore phase

Although slightly more teachers made comments about the Engage phase than the Explore phase, the total number of comments for the Explore phase far exceeded the Engage phase in that the Explore phase always had at least two lessons and sometimes three. When discussing whether the purposes of this phase were mentioned by teachers, the phase was considered as a 'whole' and not as separate explore lessons.

Teachers' responses indicated that each of the three purposes were addressed or implied by some teachers across most units. Teachers' comments suggested that all units provided experiences of the phenomenon or concept. Most teachers did not indicate that students explored and inquired into their *own* questions and tested their *own* ideas, although there were units which were exceptions. In contrast, most teachers did report that students investigated and solved problems.

Purpose: Provide experience of the phenomenon or concept

In all units most, and sometimes all, teachers indicated that this purpose was addressed. Usually this phase involved observations and reporting, and sometimes predicting, testing and fair-test investigations (especially in *Marvellous micro-organisms*). Teachers made numerous comments that related to this purpose. Some typical examples from *Marvellous micro-organisms* are:

A comment that captures what many teachers felt about this unit was:

> … this proved to be a fantastic way to learn about micro–organisms/ mould/fungi. The students were rapt, loved all the experimenting involved too. Helped them test and see if their predictions and logical thought processes were correct or not (19G *Marvellous micro-organisms*).

This unit was unusual in that two teachers commented on the feedback item called 'writing investigation questions'. Some teachers added: "… the investigation was the focus of the sessions. The most successful activity for unit – yeast – excellent activity, students had sound understanding of outcomes" (T2 *Marvellous micro-organisms* L2); "An excellent lesson to ensure that students understand how to test scientifically" (T5 *Marvellous micro-organisms* L2); and "Students excited and talkative about experiments" (T21 *Marvellous micro-organisms* L2).

In the Explore phase, apart from the above, there were a few comments indicating that students were designing their *own* investigations: "Use(d) a scaffolding investigation sheet, to get children to think about what equipment they may need, rather than be told" (T12 *Marvellous micro-organisms* L3) and

> Children designed their own fair test using procedure from L2 as (a) guide. Came up with similar to RS2 (Resource Sheet 2). Was great assessment of knowledge of fair testing and procedure genre (T4 *Marvellous micro-organisms* L3).

The concepts of physical and chemical change were also mentioned or implied as in "Children wanted to know about carbon and oxygen atoms and chemical reaction taking place"(T5 *Marvellous micro-organisms* L4), with teachers also commending the learning value of 'procedural text' (T2 *Marvellous micro-organisms* L2) and science journals ("to track change in scientific understanding") [T4 *Marvellous micro-organisms* L2]).

In *Weather in my world* a small number of teachers felt that this purpose may not have been met. An interesting observation here (and elsewhere in these analyses) was that teachers could markedly disagree about an aspect of a unit, for example:

> In lesson 3 several teachers had difficulties and one (T13) omitted the lesson: comments included: "This lesson proved too difficult. I reduced it to talking about temperature; used the words hot, warm, cool and cold and we had pictures for each of these types of weather conditions. Children (were) encouraged to find out temperature at home" (T7 L3).
>
> The children loved being weather detectives. Engaged in observations. Weather terms taught are becoming part of their every day language. (T9 *Weather in my world* L2) (and later)… Children could easily identify with red & blue for hot and cold. They use the class thermometer to read the temperature. (L3)

Purpose: Explore and inquire into students' questions and test their ideas
It was less common for teachers in the Explore phase to make reference to explorations of students' questions and/or the testing of their ideas. In some units students did explore and inquire into their own questions. On more occasions it was clearer that students tested their own ideas, rather than any questions they posed. In some units, when ideas were tested and questions were the focus of inquiry, it appeared to be the teacher or the *Primary Connections* lessons that were the source of ideas and questions asked (*not* the students).

Strong indications that students' ideas were tested <u>and</u> their questions explored
There were several units where this purpose was apparent and others where it most likely occurred. The number of teachers referring to this purpose varied considerably across units (e.g., *Water works* where it was relatively common to *What's the matter?* and *Spinning in space* where perhaps one or two teachers made reference to it). Rarely were there references to students' questions: "Constructed a terrarium to illustrate water cycle as prompted by children's questions" (T8 Water works L3).

Comments indicating the 'testing of ideas' were more readily identified–two examples were: "Session 1 Children very switched on and enjoyed the lesson, they had fun testing their predictions…" (T17 *Water works* L3); "… predicted what might happen on different surfaces before watching as a class" (T11 *Water works* L3). When fair testing was mentioned, it sometimes implied the testing of students' ideas; for example, fair testing predominated in the *Marvellous micro-organisms* S3 unit and it may be implied that at least seven teachers' comments suggested students were testing their ideas if not exploring their own questions, as in "Step 2 resulted in very interesting ideas, children wrote own ideas in science journals to track change in scientific understanding" (T4 *Marvellous micro-organisms* L3). Inquiring into students' questions was not as apparent in *Electric circuits* S3 but may have occurred when students were testing their ideas, a situation strongly implied by at least 7 teachers in lesson 4. The most obvious instance was when students engaged in the PROE (Predict, Reason, Observe and Explain) strategy:

> Students completed their own PROE record for their science journals, then contributed to a shared group PROE record for sharing in the class science journal… Students redrew cut away diagram of torch and was interesting to see the growth in their understanding… Such excitement when the first globe was lit! (T3 *Electric circuits* L4)

Units with more of a focus of students testing their ideas (rather than answering their questions)
Other units included the testing of students' ideas, but inquiries into their own questions were more problematic (although they still may have been present). An example from *Change detectives* was:

> The students counted the number of seconds before they could smell it and also the number of seconds it took to evaporate – the porous newspaper was first but *the students initially thought that this would happen to the white paper first – because it was cleaner.* They recorded the length of time for the perfume to evaporate depending on the amount – 1 drop, 2 drops etc used. (T10: Explore Lesson 2 *Change detectives*, italics added)
>
> (and later with the same teacher)
>
> We added an extra bottle of straight water for this. We also dissolved a Panadol tablet as well as a Berocca tablet as the results could more easily be seen. The students seemed to understand the chemical reaction

that occurred. We also did teabags. – one in hot water and one in cold water and recorded the length of time before the water was coloured. (10: Explore L3 *Change detectives*)

Testing ideas is obvious here (although in the 'tablet' extract it may have been the teacher's ideas).

There were a few units (*On the move, Plants in action* and *Staying alive*) where this purpose was not apparent.

Issues raised about the purpose 'Explore and inquire into students' questions and test their ideas'
In some of the units teachers suggested possible reasons for why students' questions were rarely raised or explored. In the Engage phase it was mentioned that very young learners may have difficulty in this regard. In *What's the matter?* in the Explore phase, six (of 9) teachers referred to students' limited language. This may account for the few references to student questions; for example: "… (students) found it hard to guess material of object" (T5); "Needed to go right back to basics with vocabulary – eg hard/soft" (T7); "Took them a while to get the hang of the words (using descriptive words)" (T10); and "Children needed lots of prompting with descriptive words" (T12). Limited vocabulary was also perceived by a few teachers as a stumbling block in *Material matters*. These difficulties align with teacher reports in the literature about properties of objects and materials, but there are ways forward (see, e.g., 'language use' in Skamp, 2012b). These responses do clearly indicate that students' ideas were sought, but that teachers rarely used the language of 'testing students' ideas' or having them raise questions about objects and materials (apart perhaps for Ts 5, 7- see above*)*.

In *Earths place in space* there are also suggestions as to why teachers may not have more regularly mentioned or implied that students' ideas were tested. In this unit, a few teachers indicated that students were not able to appreciate the role of exploring different mental and physical models (T12) (i.e., could there be more than one model that would explain observations). In other instances, the teacher did not encourage their students to pose questions and/or explore ideas: "Also they already knew how the Earth, Moon and Sun move in relationship to each other and couldn't see the point in the activity (RS4 Part 2)" (T12) and "Taught the students about how constellations came into being but did not really engage them in higher order thinking, explanation" (T11).

Purpose: Investigate and solve problems
This purpose was obvious in the Explore lessons in several units. As outlined above, the 'problems' may not have been the students, but many investigations still occurred and problems were 'solved'. An obvious example was in *All sorts of stuff* where this purpose was addressed whenever the teachers referred to fair testing lessons (which was mostly very positive): this occurred often in four Explore lessons. Some comments were more explicit (Ts 2, 8, 10, 22 [L2], 6 [L3], and 22 [L4] and examples are:

> Worthwhile activity as children were amazed at own predictions at what did not rot (T2, L2)
>
> Also difficult to cut all materials into 'fair test strips' (It did become a good discussion, re fair test and tensile qualities) (T 6, L3)
>
> … students were able to identify new understandings. Many were surprised at the differences between predictions and results (22 lesson T 4)

It was clear that *Marvellous micro-organisms* S3, *Electric circuits* S3, *Push-pull* S1 and *Smooth moves* S2 units also provided numerous opportunities for students to meet this purpose with at least:

- ten *Marvellous micro-organisms* teachers specifically referring to the value of fair testing and the various micro-organism experiments;
- seven *Electric circuits* teachers referring to students investigating to solve problems about how a torch works and completion of a circuit;
- seven *Push-pull* teachers engaging students in investigating problems associated with forces;
- five *Smooth moves* S2 teachers making reference to students investigating the impact of pushes and pulls as well as the effect of friction. There were some exemplar instances of how students attempted to be fair in their testing of ideas:

> An excellent activity that worked well using the tomato cans. In working on defining a fair 'big and small' push we did averaging for the three small pushes and then the same for the big pushes. The data was excellent to view, especially when one of the three results was very different and asking why this was so… (and later) Some used a blackboard ruler like a pool cue and pulling back a

> certain number of cm in an attempt to define small and large pushes. Most did it successfully on the width of the table simply by pushing. (T8 *Smooth moves* L2)

It is worth noting, as one teacher remarked, that for such inquiries to be most effective there is a need "for proper discussion, questions, making sure instructions are understood etc." (4 *Smooth moves* L3)

It may be assumed that most of the remaining units provided students with experiences of the focus phenomena, but that, in general, their questions were not mentioned, although their ideas may have been tested. For a few units this purpose was far less apparent, namely, *Material matters*, *What's it made of?*, *Plants in action* and *Weather in my world*.

The Explore phase: Discussion of issues raised by teacher feedback
In most units there were real opportunities for students to raise questions, test their ideas and investigate and 'problem solve' yet the first mentioned was only occasionally referred to, while teachers referring to the latter two varied considerably across units.

Encouraging students to raise questions and handling students' questions
It is worth noting that only two teachers commented on the strengths and weaknesses of the 'Investigation Skills' section in the feedback proforma titled 'writing investigation questions'. This could mean that very few teachers have considered how to 'turn' students' questions so that answers may be found by using science inquiry skills. Turning questions towards investigation is an acquired skill (e.g., see Harlen & Jelly, 1989; Skamp, 2012d) and even when questions were raised in some of the units it is plausible that some teachers may not have known how to handle them in this way.

In several units it was not clear that it was students' questions that were investigated. The 5E model underpinning the *Primary Connections* units requires that students will "…use science concepts to develop explanations for the science phenomenon" experienced in the exploration phase (Hackling & Prain, 2005, p.26). Therefore, in order to meet this goal, it may not always be possible to follow students' questions and test their ideas; however, many teachers were able to encourage the latter and some the former. Apart from *Primary Connections* lesson steps that encourage teachers to be aware of student questions (as in the use of the chat board and other approaches or techniques), there is the goal of creating a 'question-asking' and 'problem solving' ethos in classrooms. This was clearly present in some of the teachers' comments but not apparent in others.

Factors that may have influenced the successful implementation of the Explore phase
In general this phase was very successfully implemented. Various Explore tasks tended to be more successful than others. In these teachers' own comments, this would seem to be related to the:

- the physical nature of tasks especially with younger learners (e.g., using the senses in *What's the matter?*, *Staying alive*), but also with upper primary years;
- readily observable changes occurring in the activities, such as "dramatic change of early and late shadows" [T5, *Spinning in space*]; however it does need to be realised that, for older learners, sometimes no change is also worth noting, as in 'no observable reaction when materials or substances are added together' as reported in *Change detectives*;
- clarity and appropriate level of the conceptual ideas within the phase and that the suggested physical tasks directly related to these ideas (e.g., ball sizes and distance in *Spinning in space*);
- variety in activity type;
- helpful questions provided in *Primary Connections* units;
- value of the 'investigation planner'(the majority of teachers were very familiar with fair testing);
- simple equipment being required; and
- ICT suggestions that readily translate into classroom tasks.

Factors that may have hindered the successful implementation of the Explore phase
Teachers referred to several factors that they thought detracted from various *Primary Connections* tasks. These included:

- too much time devoted to discussion of ideas (e.g., T1 *Staying alive*);
- complexity of ideas within parts of units (e.g., in *Earths place in space* interpreting evidence from models of the possible movements of the earth, sun and moon);

- ICT sites that either are inaccessible or not readily translatable into classroom tasks (as in *Earths place in space*); and
- Limited vocabulary or ability to use some skills (mainly younger students).

Of value to teachers in the Explore phase may be a guide to levels of scaffolding (e.g., Hodson & Hodson, 1998) and ways that teachers can handle students' ideas (e.g., see some of Harlen's (2009) teachers' roles and Harlen, 2001).

Explain phase

The Explain phase always involved one lesson. Although all phases in the 5E model are important, this phase is pivotal (Marek, 2009). The Engage and Explore phases provide interest and experiences to get students thinking about how an aspect of their world works. Teachers are to *help draw together* (not necessarily directly 'explain' although this phase can include teacher explanation) the range of ideas that students have been encountering in this (Explain) phase. Students are then expected to apply and extend the conceptual idea that is the focus of the sequence in the next (Elaborate) phase before the teacher and students evaluate the success of the sequence, particularly in terms of the conceptual understanding of the unit's central idea.

Teachers' responses indicated that each of this phase's purposes were addressed or implied by some teachers across most units. All units used conceptual tools to construct explanations of the concept. All but two units included some teachers who used multi-modal explanations and similarly all except three units had some teachers who involved their classes in comparing explanations from different groups. With the possible exception of *What's the matter?* ES1, all units included some teachers who ensured the scientific view was considered.

The essence of the Explain phase is captured in this teacher's comment:

> The discussions around why we categorise were amongst our best of the unit. Whether it has taken this long to assimilate the information or the fact I was more comfortable seems to have had a bearing on this last component. There were no challenges. The children coped with this section very well. I wonder whether it's because we "revised'" rather than added further investigations that the students worked very well with this notion of classifying…The students enjoyed the revisiting (of) the earlier work they had completed such as the Mess Scene Investigation and remembering how "revolting" the frozen milk appeared. I also believe that whole sorting out process which the Changes card sort and their discussion allowed for placement of what the students had been learning into organised understandings. This activity was beneficial because (it) organised their own concepts and gave them the time to do it. (9 *Change detectives* Italics and parentheses added)

Characteristics of the Engage phase italicised emphasise that this phase is to "provide opportunities for students to use their previous experiences to recognise misconceptions and to begin making conceptual sense of the activities through the construction of new ideas and understandings" (Bybee, 2002, p.32). It stresses why it is important that this phase not be omitted.

Purpose: Introduce conceptual tools that can be used to interpret the evidence and construct explanations of the phenomenon

At least 15 categories of conceptual tools were mentioned in this phase. The most common tool was teacher explanation and/or class discussion (n=37 teachers/across all four (4) strands), and referred to more in the 'Energy and change' strand. Other tools referred to by ten or more teachers were; role-play/plays (n=17/2) but only in 'Earth and beyond' and 'Energy and change' strands; writing (unspecified, journal, explanation text; sentence completion) (n=16/4); and 3-D visual aids and/or manipulatives (n=10/4). Of interest is that ICT tools (internet, computer graphics/animation and PowerPoint) were referred to by seven teachers across three strands (not 'Energy and change'). Some units used a wider variety of conceptual tools than others and some teachers showed real initiative in their efforts to facilitate understanding of the central ideas in the units. Role-play was most popular in *Electric circuits* and *Smooth moves* and it is significant that at least one teacher mentioned discussion about the limitations of role-play. Some typical comments were:

> The role-play really demonstrated how circuits work and clearly showed the parts the battery, electrons and globe play. This was an excellent activity to consolidate concepts discovered during L4. (T3 *Electric circuits*)

> This was an excellent way to formalise the concept. They all wanted a turn to be the battery and globe. It was important to discuss the limitations of the role-play. (T17 *Electric circuits*)

> This was a terrific lesson, the kids loved the role-play… It was a great way to see what they understood – or didn't understand – but because it was explain stage we discussed it at length. (10 *Smooth moves* emphasis in original)

Explicit reference to evidence

Although interpreting evidence and constructing explanations overlap, it was rare for teachers to include comments that directly referred to focussing on 'evidence' per se, although it would have occurred in some lessons. Examples where it was more obvious were uncommon and some of these are outlined below.

Several *Earths place in space* teachers indicated students were appreciating the concept of 'evidence' with two teachers (T3, T7) directly mentioning the term and two (T8, T9) implying its discussion:

> Developing understandings that scientists from the past are real people and their theories were based on evidence (T7 *Earths place in space*)

> Learning about Galileo – the students were fascinated, and appalled by the fact that somebody could be jailed for expressing an opinion – especially as it was true. They became quite obsessed with the injustice of it and it re-ignited their enthusiasm for the unit. (T9 *Earths place in space*)

Other teachers who made, or clearly implied, a reference to evidence were:

- At least three *Change detectives* teachers (Ts 5,6,9) as in "This was an excellent challenge in terms of problem solving. We spent a lot of time generating ideas on what/how they could affect the candle and how long it would burn for" (T9 Explain *Change detectives*).
- In *All sorts of stuff* claims would appear to be justified in several comments (Ts 4, 6, 10. 11, 22 and probably 2); examples included: "With all (the) background on plastics, students were able to write well reasoned expositions (T4); "Nova website useful for information for PMI… Class really got into presentation of facts about plastic with a variety of class plays or shows" (T11).

Purpose: Construct multi-modal explanations and justify claims in terms of the evidence gathered

There is growing evidence that encouraging students to represent their understanding in more than one mode assists conceptual development (Tytler & Prain, 2010); furthermore, teachers can scaffold learning by using more than one mode. The forms that modes may take include descriptive (verbal, graphic, tabular), experimental, mathematical, figurative (pictorial, analogous and metaphoric) and kinaesthetic (embodied, e.g., use of gesture, and physical action). Some tasks by their nature will include more than one mode such as role-play or simulation (e.g., it could be movement and verbal).

The units in which most teachers used a multi-modal approach were *Electric circuits* (n=10/at least three (3) combinations of modes), *Spinning in space* (n=6/5), *Smooth moves* (n=6/2) and *Change detectives* (n=4/1), and three of these units were very popular with students and teachers. Of interest is that two units that received mixed comments from teachers (*Weather in my world, Push-pull*) included no comments that referred to more than one mode in this phase; in both cases some teachers referred to conceptual difficulties experienced by some students. Further, across all the units, examples can be found of most (if not all) modalities, including kinaesthetic. Although the content area can affect what modalities might be considered, this does suggest that many modalities could be used in most content areas.

Purpose: Compare explanations generated by different students/groups

Often this purpose was not directly mentioned; although, when discussion occurred it may have eventuated. Discussion/conversation was mentioned (or strongly implied) with different degrees of frequency in different units. At other times teachers did not directly make reference to discussion or students sharing explanations, although it probably could be implied if students were involved in role play and similar activities. At times the sharing of students' explanations was more explicit, but often there was only one teacher within a unit that mentioned it happened. Two examples were:

- *Plants in action* S2 (T6): "…Sharing the representations with another class was a Wow. Children had experience of sharing".
- *Smooth moves* S2 (T10):

> This was a terrific lesson, the kids loved the role-play, but boy it takes up a lot of time, particularly the role-play because everyone wanted to show everyone else what they did (all nine groups). It was a great way to see what they understood – or didn't understand – but because it was explain stage we discussed it at length. … Many of my kids did not know about energy.

Units in which no teachers directly indicated that explanations were compared were *What's is made of?* ES1, *Push-pull* S1 and probably *Weather in my world* ES1.

Purpose: Consider current scientific explanations
In determining if this purpose was addressed or implied, two categories were developed. If teachers made some reference to the conceptual content in the unit in the Explain phase, then it was considered to be evidence that the scientific view was part of the teacher's thinking. If other comments suggested that the conceptual content was addressed but there was no mention of the content, then a judgement was made as to whether the scientific view was implied.

Units where the scientific view was most obvious were *Electric circuits*, *All sorts of stuff*, *Material matters* and *Change detectives*, followed by *Smooth moves* and *Push-pull*, while teachers did not appear to mention this purpose in *Weather in my world* and *What's it made of?*, and rarely in *On the move*, *Staying alive*, *Plants in action* and *Marvellous micro-organisms*. Although not consistently the case, it may be that teachers in lower primary years are not focussing on students organising their thinking around the units' key conceptual foci as much as upper primary year teachers. Other possibilities for these differences could be that: firstly, some *Primary Connections* units' science conceptual foci are more clear cut as in concepts and understandings like electric circuit (*Electric circuits*), solids, liquids and gases (*Material matters*), properties of materials and their uses (*All sorts of stuff*), physical and chemical change (*Change detectives*) and forces (*Push-pull* and *Smooth moves*); and, secondly, there were distracting factors that moved the focus elsewhere as in simply watching seeds germinate and plants grow (*Plants in action*) or some teachers having difficulties with implementing units (*Earths place in space*). In some instances, though, when teachers and/or their students found the concepts challenging, they focussed more on the key ideas with their students, as indicated in some comments from the *Push-pull* unit.

Teachers generally commended the *Primary Connections* explain strategies that were suggested to help students 'organise' their thinking towards the conceptual focus of the unit. The formation of the scientific view was especially assisted by role play in *Electric circuits* and sorting tasks in *Change detectives*, as well as, when required, teacher explanation (*Push-Pull* and *Smooth moves*). Choice of the most effective strategies will, to some extent, be dependent on the nature of the science concept or understanding, as these examples show.

Teacher actions in ensuring the scientific view is considered need to be subtle[7]. The 5E model does not indicate that the scientific view be 'transmitted' to students. Rather, teachers help students clarify their thinking in the Explain phase; students are active learners in all phases of the 5E cycle, an interpretation emphasised in early research related to the learning cycle (Glasson & Lalik, 1993). It would seem from teacher comments that this approach was appreciated, since there were no suggestions that direct transmissive teaching occurred. Although, teacher explanation had its place when required.

Elaborate phase
The essence of this phase was summed up by a teacher who said, "It was good to apply tests and understandings to different situations" (T1, *Push-pull*). In this phase some teachers' comments indicated they appreciated this requirement, while many others left it unsaid.

Purpose: Use and apply concepts and explanations in new contexts to test their general applicability
Using and applying concepts and explanations (mentally 'organised' by students in the Explain phase) in new contexts to test their generalisability was not explicit in many teachers' comments across several units. If comments that implied this purpose are also considered, there were still units that may have rarely mentioned the use and application of ideas in new contexts, such as *Weather in my world*, *All sorts of stuff*, *Schoolyard*

[7] Teachers, while being subtle, still must have as an explicit goal, the clarification of the underlying conceptual idea, and once this has emerged (usually through the facilitation by teachers) of students 'organising' their thinking, then teachers can be explicit in ensuring that the conceptual idea has been stated.

zoo and *Smooth moves*. Teachers (at times) may have been more focussed on students successfully carrying out fair tests that they did not mention how the tests related to the conceptual purpose of the unit. To answer a scientific question or solve a problem, students need to bring together their understanding of science concepts, their knowledge of and ability to apply skills, and an understanding of and ability to apply (concepts of) evidence (Feasey, 2012, p.65) and, as has been emphasised for many years, science learning is less effective if process and conceptual understandings are not taught together (Miller & Driver, 1987). Teachers' comments may indicate that this balance was overlooked.

As noted, there was not necessarily a connection between teachers referring to key concepts in the Explain phase and then revisiting them (in their comments) in the Elaborate phase. Teachers probably commented on what caught their attention about activities in the Elaborate phase and, except for a minority, this 'conceptual' purpose (of the phase) was not uppermost in their thinking. There is also the possibility that some teachers may have been unclear about the intention of this purpose and hence did not focus on how the Elaborate tasks may have been using and/or applying the units' main (conceptual) idea(s).

An example where teachers did apply concepts in different contexts was the following:

> Application of force ideas to movement. On the move was a unit where most teachers combined comments about investigations with the underlying 5E concept(s) as in "Took things outside and tested on slide (roll, slide, tumble), students traced objects onto large piece of paper and labelled how the item moves – some wrote, some drew" (T8); "Interesting concepts came up such as children predicting one container would roll in a circle because the top was wider than the bottom; Children then wanted to test other round items" (T1); "LS10 – using 2 hoops, made equivalent of Venn Diagram on floor and organised the objects tested (roll; slide)" (T10 On the move). In the two subsequent units PP and Smooth moves this, in general, did not occur although a teacher did say "It was good to apply tests and understandings to different situations" (T1, PP)

Purpose: Reconstruct and extend explanations and understanding using and integrating different modes, such as written language, diagrammatic and graphic modes, and mathematics
This second purpose, using various modes to reconstruct and extend understanding, developed in the Explain phase, was mentioned in most units across all strands. Teachers mentioned using linguistic (verbal, written), kinaesthetic, mathematical (graphical, measurement, tabular) and visual (pictorial, diagrammatic, tabular) modes. Furthermore, on many occasions, it was reported that several modes were used and/or integrated. Several teachers in each unit used a variety of modes, but this was less common in *Weather in my world* and *Material matters*; these were two units that some teachers indicated posed learning difficulties for their students, such as an inability to express ideas about the topic because of a lack of adequate language. It poses the question, would the use of different modes have helped?

Two examples of how some of these modes were used and/or integrated to extend understanding and explanations included: "Students completed large graph, then created individual graph, discussion was interesting as children did not know a lot about saving water, so had an extra lesson on this topic" (T11, L6 *Water works*) and "Optional role play was great to give the students an idea of what was required. I used the role play and various concept cartoons as stimuli to assist students in their investigations of switches in circuits" (T13 *Electric circuits* L8).

Evaluate phase

The Evaluate phase always involves one lesson. There was strong evidence for students and teachers reviewing their conceptual understanding (but not their skills), but it was less common to read that teachers had provided opportunities for students to reflect on their learning (as in, the learning processes used) and their understanding and skills. A distinction has been drawn here between reviewing and reflecting, as implied in the purpose statement. In general, providing evidence for changes to students' understandings, beliefs and skills was not as evident and was not mentioned in four units (*What's the matter?, Material matters, Weather in my world* and *Earths place in space*). This latter purpose required teachers' comments to include some reference to 'changes' in students' learning. The response rates for the Evaluate phase were far less than for the other phases (for most units). The generally low response rate does suggest that quite a few teachers did not implement this phase.

Purpose: Provide an opportunity for students to review and reflect on their own learning and new understanding and skills

In ten units, two thirds or more of teacher comments (102 in total) referred to reviewing student understandings, with *Earths place in space* being the only unit with less than a quarter of responses. In contrast to this focus, only ten teachers (across 4 units) mentioned reviewing science inquiry skills (but this can be explained by *Primary Connections* referring to summative assessment of science inquiry skills in the elaborate phase). About twenty teachers (around 10 percent) encouraged students to reflect upon their learning in the unit, including learning processes and their feelings about the unit.

Teachers referred to a wide range of review strategies apart from the more common discussion, straight forward written responses and quizzes. These included novel approaches such as a 'newspaper' (*Water works*), a design task (*All sorts of stuff*, *Electric circuits*), grouping using hoops (*On the move*), thinking hats (*Smooth moves*), an electric circuit problem (*Electric circuits*), interactive crossword (*Marvellous micro-organisms*) and creating an invertebrate (*Schoolyard zoo*). Some teachers also referred to using student journals for this purpose (Push-pull and Marvellous micro-organisms). Several of these were met with enthusiastic comments from teachers (e.g., plant life jumble [T21 *Plants in action*]; 'What am I' activity (T11 *Material matters*).

Teachers encouraged students to reflect on their learning in a variety of ways; for example, "write reflections (in their science project book) in work after each session" (T2G *Marvellous micro-organisms*); "Fantastic (reflection resource) sheet – out of 80 students, 1 child said he did not like science (hates school), 3 said they loved it but felt they did not do well and 90% said they love it but would like more hands –on"(T15 *Electric circuits*); "…Then children sat in small groups and reflected on the unit using the Thinking Hats" (T6 *Smooth moves*); and "Students were able to relate well to what they like and reflect that in their responses. They loved learning about the planets" (T11 *Earths place in space*).

Assessing science outcomes: Some illuminating issues

Among the issues that these teachers' comments raised were: (1) varied assessment processes in the Evaluate phase are sometimes required to assess understanding (e.g., "…to get an accurate picture of (student) understandings. Some couldn't demonstrate their understanding in diagrams but could answer questions orally" [T3 *Push-pull* L9]); (2) authentic assessments, if possible, are preferred (e.g.,"Used World Environment Day topic of Rainforests as topic for which children were asked to design a home and clothing, what materials you would use and why [T18 *All sorts of stuff*]); (3) there is a need to distinguish knowledge from understanding (the following teacher distinguished 'facts' from 'concepts', which is the focus of the 5E schema "… kids really struggled with the idea of not just giving a fact instead of explaining a concept "(T13); (4) 'Nature of Science' (NoS) outcomes can be assessed (One teacher [T11 *Earths place in space*]) also implied that NoS outcomes may have been (inadvertently) assessed- see the following reference to 'arguing'- (albeit having difficulty doing so): "Children had difficulty arguing the point of view that the earth was the centre as they really did not have enough background knowledge"); and (5) quality and novel assessment can take time that teachers may not have (novel assessment [e.g., student dialogue in a play, which in *Earths place in space* was meant to determine students' ability to use evidence etc.] takes time and can be an issue).

Purpose: Provide evidence for changes to students' understanding, beliefs and skills.

Fewer teachers commented they had collected evidence of changes in student understanding, beliefs and skills. With reference to student understandings, some teachers made reference to this purpose except in the units *Weather in my world* and *What's it made of?* Several teachers' comments referred to being able to "gauge individual progress in learning" (T19 *Electric circuits*), "see where students were at in their learning" and that students were "consolidating their learning" (T4 *Schoolyard zoo*; T3 *Electric circuits*). At times, teachers included reference to the conceptual area in which change was noted. Examples included students learning "so much about air and moving things" (*Smooth moves* T4) and what they "had learnt about change" (T3G *Change detectives*).

Two observations about evidence of changes in students' learning

An instructive comment was made by a teacher who clearly knew what they were looking for in students' assessment tasks. It emphasises that teachers need to be clear about the conceptual foci they are assessing:

> I had to keep sending the kids back to their desks to include more information and kept pointing to our word wall. *Many of the students did not include friction* and could not identify correctly where it would be. (T5 Smooth moves emphasis added)

Some teachers did indicate the overall impact that *Primary Connections* can have on students' learning. One referred to the longer-term learning that appeared to have occurred:

> Had to carry this session into Term 2. Students surprised teacher with the amount of information they had retained. All understood what the cycle represented. (T6 Plants in action)

Elsewhere in this paper are comments that indicate that students who have studied two sequential *Primary Connections* units on the same conceptual area have retained some understandings from the pre-requisite unit.

(3) The constructivist, inquiry, language and assessment foci in *Primary Connections* (following Harlen, 2009)

> *Primary connections* is based on an *inquiry and investigative approach* in which students work from questions through investigations to constructing explanations and is therefore consistent with *contemporary constructivist learning theory*. Students are given the opportunity to *represent and re-represent their developing understandings* using a wide range of texts and information and communication technologies (ICTs). *Assessment is integral* with teaching and learning. Students representations of their developing understandings provide opportunities for *teachers to monitor students' learning progress and use this information to facilitate further learning*.
>
> (Hackling & Prain, 2005, p.8, italics added)

Primary Connections is underpinned by an approach based on constructivist learning theory, in which is embedded an inquiry-oriented and investigative approach. Learning is, in part, developed through language ("Students … represent and re-represent their developing understandings using a wide range of texts…"). Assessment, particularly formative assessment ("…teachers to monitor students' learning progress and use this information to facilitate further learning"), is embedded in the initiative. These four areas, constructivism, inquiry, language (especially 'talk') and formative assessment have been argued by Harlen (2009) to be the basis of an emerging, and more effective, pedagogy in science. These four areas were the lenses through which teachers' comments about implementing *Primary Connections* trial units were analysed. There is some overlap between Harlen's lens and the detailed 5E analyses.

For each area Harlen identified learner roles (see Appendix 2). The frequency with which these roles were suggested in the teacher feedback for each area is outlined next.

- *Constructivist emphases*
  All of the constructivist leaner roles were present in the implementation of some units. Some roles were met with greater ease than others, while some were more difficult to discern (see Table 3). Of these learner roles those requiring students to deal with 'evidence' were less apparent; it is problematic how little emphasis teachers were placing on students providing 'evidence' for their thinking. It may be present in *Primary Connections* lessons, but it was not obvious in the teacher feedback comments. Also the application of ideas to new situations, while present in some classrooms, may need further clarification of the purpose of the elaborate phase so that more teachers are fully aware of the understandings they are helping students to use or apply in new contexts. Finally, developing 'bigger' ideas from 'smaller' ones may have been incidental to teachers' thinking, although there were some examples of it.

Table 3: Extent to which the constructivist learner roles were explicit/implicit in teachers' feedback comments across 16 units

Learner role	Extent
Learning actively (mentally and physically) is obvious in most units	Very high
Discussing own and others' ideas	Very high
Using ideas to try to understand new events/ phenomena	Moderate
Reasoning about evidence	Low
Modifying ideas in the light of evidence	Low
Developing 'bigger' ideas from 'smaller' ones	Moderate

Meaning of ‘Extent’ ratings: If about 5 or more imply the role in 75% or more of the units then ‘Very high’; 50% or more ‘High’; 25% or more ‘Moderate’; less than 25% ‘Low’.

- *Inquiry emphases*
  There is evidence that all of the inquiry leaner roles were present in the implementation of most units (see Table 4). On the basis of many teacher comments there is an ethos of inquiry in many *Primary Connections* classrooms; although, those learner roles requiring students to deal with ‘evidence’ were less apparent. There were fewer mentions of some science inquiry skills (e.g., hypothesising) and less guided investigation was far less common than guided investigation.

Table 4: Extent to which the inquiry learner roles were explicit/implicit in teachers’ feedback comments across 16 units

Learner role	Extent
Collecting evidence (first hand and from secondary sources) about the world around	Very high
Using enquiry skills (observation, prediction etc.)	Very high
Learning actively (mentally and physically)	Very high
Reporting and discussing evidence	High
Reasoning with others about how different ideas fit the evidences (argumentation);	Low
Reflecting on learning processes and outcomes	High

Meaning of ‘Extent’ ratings: If about 5 or more imply the role in 75% or more of the units then ‘Very high’; 50% or more ‘High’; 25% or more ‘Moderate’; less than 25% ‘Low’

- *Language/talk emphases*
  All of these leaner roles were present in the implementation of all units (see table 5). ‘Using language appropriate for explaining scientific phenomena’ could be more readily discerned since teachers often mentioned students’ development of vocabulary and ability to describe what they were observing and testing. It was a strong focus for most units. Students explaining their ideas to others could be ascertained at times, but the extent to which students were ‘Listening and responding to others’ ideas’ was more difficult to discern from teachers’ comments.

Table 5: Extent to which the ‘Language/Talk’ learner roles were explicit/implicit in teachers’ feedback comments across 16 units

Learner role	Extent
Explaining their own ideas to others with examples where appropriate	High
Using language appropriate for explaining scientific phenomena	High
Listening and responding to others’ ideas	Moderate

Meaning of ‘Extent” ratings: If about 5 or more imply the role in 75% or more of the units then ‘Very high’; 50% or more ‘High’; 25% or more ‘Moderate’; less than 25% ‘Low’.

- *Assessment emphases*
  Teachers’ comments that related to assessment were interpreted from a wider perspective than Harlen’s learner roles. In broad terms, teachers referred to assessment in each of the 5E phases, although more frequently in the Evaluate phase. In the 5E phases diagnostic assessment is mainly focussed in the earlier phases (mainly in the Engage phase), formative in Explore and Explain phases, and summative in the Elaborate and Evaluate phases (AAS 2008). Revealing students’ ideas and beliefs, a purpose of the Engage phase, is a component of diagnostic assessment. The 5E analyses indicated some teachers endeavoured to recognise students’ entering conceptions. The two purposes of the Evaluate phase had a summative assessment role, and focussed on students’ science understandings, whereas the Elaborate phase focuses on summative assessment of science inquiry processes and skills. In the following

comments, aspects of assessment not identified in the Engage and Evaluate phase (see earlier) are the focus.

Some of the key 'assessment' findings were:

- *Primary Connections* is helping some teachers to rectify an imbalance that can occur at the primary level. That is, to undertake thorough assessment only in the areas of literacy and numeracy. As one teacher said:

> Teaching these lessons has enabled me to feel confident about writing students' reports and commenting upon their scientific understanding about space (T4G *Earths place in space*).

- Teachers' comments referred to diagnostic and summative assessment in the Engage and Evaluate phase (although they very rarely used this terminology). Beyond these phases, there were at least seven of the 16 units analysed in which teachers made three or more readily discernable assessment comments (EP S3; *Material matters* S1; *All sorts of stuff* S2; *Change detectives* S3; *On the move* ES1; *Smooth moves* S2). Some of the more general assessment aspects teachers mentioned include:
    - On a few occasions teachers referred to the positive influence on students' science learning of completing more than one *Primary Connections* unit.
    - Although not regularly mentioned, several teachers did refer to "linking assessment to learning outcomes" (T2G *Spinning in space* S2). Sometimes they referred to how successful the unit (or aspects of it) had been. For example, "Excellent learning outcomes with children understanding why different materials are used for a particular purpose" (T14G *All sorts of stuff*) - a summative comment, and "students responded well to these questions. Good sequence of activities. Students were able to achieve lesson outcomes. (7 *Staying alive* L3 Explore) - a formative assessment remark.
    - Several teachers commented on the limited time to complete assessment tasks.
    - In the analysis of the Evaluate phase, teachers (and students) reviewed, and to a lesser extent reflected on, students' learning. Comments indicative of the overall assessments of student learning outcomes made by teachers referred to students' enjoyment of *Primary Connections* units, their conceptual progress and to a lesser extent their development of science inquiry processes and skills. It is of interest that 'enjoyment' is often mentioned by teachers as an outcome. In *Primary Connections* units, the lesson outcomes focus is on students' understandings and inquiry skills, although an underlying premise of *Primary Connections* is that primary students will engage more with science as a school subject, and in their everyday lives, and this obviously has an affective element that cannot be overlooked (e.g., see Duit, Treagust & Widodo, 2008).
    - Teachers' formative assessment processes included teacher observation of students' science products and their involvement in science processes, dialogue with students, and more formal teacher questioning. Teachers referred to their reading of student journals (which were, in some classes, regularly used in each phase [e.g., Ts 4, 7 *Marvellous micro-organisms*]) as well as mentioning flow charts (T23 *Marvellous micro-organisms* Explain), and peer review (T5 *Marvellous micro-organisms* Explain). A search of Explore, Explain and Elaborate phases for formative assessment comments revealed that teachers often did refer to students' progress in conceptual understanding and, to a lesser extent, their science inquiry process and skill development.

Only a very small number of teachers' comments could be located that implied Harlen's (2009) formative assessment learner roles, except for 'students reflecting on learning processes and outcomes', which were the focus of the Evaluate phase (see table 6). In that phase, it was found that opportunities were provided for students to review their learning of conceptual outcomes. There were fewer mentions of students reviewing their progress in developing science inquiry skills, but some teachers were aware of this dimension. Several teachers also had students reflect on their learning outcomes across a range of categories, but reflection on learning processes was far less apparent.

Teacher-feedback comments did not appear to refer to learners 'agreeing (to) the standards of quality to apply in assessing their work' or 'taking responsibility for working towards the goals of particular activities', but it would be plausible to assume that as teachers assisted students to, for example, improve on their fair testing, that students started to become aware of the standards required for more rigorous fair testing. With reference to peer and self-assessment, they were mentioned only twice across 16 units.

Table 6: Extent to which the formative assessment learner roles were explicit/implicit in teachers' feedback comments across 16 units

Learner role	Extent
Taking responsibility for working towards the goals of particular activities	Low
Agreeing the standards of quality to apply in assessing their work	Low
Participating in self assessment and identifying their next steps	Low
Participating in peer-assessment;	Low
Reflecting on learning processes and outcomes	Low to Moderate

Meaning of extent ratings: If about 5 or more imply the role in 75% or more of the units then Very high; 50% or more High; 25% or more Moderate; less than 25% Low

(4) Evidence as to whether the Science in Schools (SiS)components (Tytler, 2003) were present

Detailed unit analyses presented in this section resulted in tables that estimated probabilities as to whether the SiS components are present in the majority of classes that were taught each *Primary Connections* unit. These estimates were based on the frequency with which teachers made reference to characteristics associated with each SiS component. From these individual SiS unit tables, a summary SiS table was compiled (Table 7).

This summary table provides an indication if the SiS component was present (or not) in a majority of classrooms. If 'Yes' is entered in the table, then this indicates most teachers' comments indicated the presence of the SiS component; if 'No' then either no comments indicated the presence or at most possibly one mention. The terms 'probably' and 'possibly' are used because exact numerical data was not available; 'probably' implies that the criteria are more than likely present in a majority of classes and 'possibly' implies that the criteria may still be present in a majority of classes, but it is less likely. It must be remembered that the presence of 'No' (in any form) in the table(s) does not mean the SiS component was absent; it means that teachers' comments did not refer to the component. Nevertheless, this analysis still provides avenues for further investigation.

This summary table suggests that:

- Some (SiS) components were met in a majority of classes across all units, namely
  Students are encouraged to actively engage with ideas and evidence
  Students are challenged to develop meaningful understandings
- Some components were met in a majority of classes across most units, namely
  Assessment is embedded within the science learning strategy
- Some components were met in a majority of classes in a majority of units, namely
  Science is linked with students' lives and interests
- Some components were met in a majority of classes usually in a significant minority of units, namely
  Students' individual learning needs and preferences are catered for
  The Nature of Science (NOS) (how science works) is represented in its different aspects
  The classroom is linked with the broader community
  Learning technologies are exploited for their learning potentialities

In drawing these inferences, it must be reiterated that teachers were not asked to indicate what happened in their classes that related to these components. The inferences are based on the content of the statements made by teachers. Of all the components, the one that is most likely underestimated is 'Students' individual learning needs and preferences are catered for' because it is unlikely that teachers would comment on this condition within the context of the feedback proforma. However, even meeting this component was mentioned by a number of teachers.

Even though four components were not identified in a majority of units, it is still a positive finding that evidence of all components was found in statements by some teachers in a variety of units. This is because of the nature of the data collected.

Table 7: Degree of likelihood that science inquiry skills criteria indicating that conditions for effective primary science learning were present in a majority of classes that trialled the analysed *Primary Connections* units[8]

Science in Schools criterion	Weather in my world	Water works	Spinning in space	Earth's place in space	Staying alive	Schoolyard zoo	Plants in action	Marvellous micro-organisms	On the move	Push-pull	Smooth moves	Electric circuits	What's it made of	Material matters	All sorts of stuff	Change detectives
Year	06	06	06		09	08	06	06	06	06	09	07	08	09	08	08
Students are encouraged to actively engage with ideas and evidence	Prob Yes	Yes	Prob Yes	Prob Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Prob Yes	Prob Yes	Yes	Yes
Students are challenged to develop meaningful understandings	Possibly Yes	Yes	Prob Yes	Prob Yes	Prob Yes	Yes	Prob Yes	Prob Yes	Yes	Yes	Prob Yes	Yes	Prob Yes	Poss Yes	Yes	Yes
Science is linked with students' lives and interests	Possibly Yes	Yes	Pron No	Prob No	Possibly Yes	Yes	Prob Yes	Yes	Possibly Yes	Prob No	Poss No	Poss No	Prob No	Prob No	Prob Yes	Prob Yes
Students' individual learning needs and preferences are catered for[9]	Poss No	Poss Yes	Poss No	Prob No	Poss No	Poss No	Poss No	Poss Yes	Poss No	Poss No	Poss No	Poss No	Prob No	No	Poss Yes	Poss No
Assessment is embedded within the science learning strategy	Poss No	Poss No	Prob Yes	Prob Yes	Poss Yes	Prob Yes	Prob Yes	Yes	Poss Yes	Prob Yes	Prob Yes	Yes	Poss Yes	Poss No	Yes	Yes
The NOS (how science works) is represented in its different aspects	No	Poss No	Prob No	Prob No	No	No	Prob No	Poss No	No	No	No	Poss Yes	Prob No	No	Prob Yes	Prob Yes
The classroom is linked with the broader community	No	Yes	Prob No	No	No	Prob Yes	Prob Yes	Poss Yes	No	Poss Yes	No	Poss No	Prob No	No	No	No
Learning technologies are exploited for their learning potentialities	No	Poss Yes	Prob No	Prob Yes	Poss No	Prob Yes	No	Prob No	No	No	No	Poss Yes	Prob No	Prob No	Prob No	Prob Yes

8 the presence of 'No' (in any form) in the table(s) does not mean the Science in Schools component was absent; it means that teachers' comments did not refer to the component.

[9] It would not be expected that teachers would include comments on this SiS component.

(5) Other implementation issues that arose from analyses of the teachers' feedback
The data were inductively analysed for any other relevant issues that may assist in the interpretation of these teachers' implementation of *Primary Connections* units. A range of issues emerged. Some of these are briefly outlined.

- Teachers held a range of beliefs about science, scientists, appropriate content and concepts in science, and pedagogy in science These would have influenced their decisions and actions when teaching science (as many studies have found, e.g., Fetters, Czerniak, Fish & Shawberry, 2002). Some examples, and/or implications, of inferred beliefs were:

    - *Re science*. Teachers did imply various beliefs about the nature of science (NoS) (e.g., not generalising too soon; findings are based on empirical evidence) but it is not clear whether they made these NoS attributes explicit. Furthermore, they referred to "*scientific* thinking and discussion" (T5 PP; T3 *Smooth moves*) suggesting it could be characterised. When science was taught using a role-play a teacher commented, "I think they liked a different approach – it was science but we were doing drama!" (T9 *Change detectives* S3 Explore). This suggests this teacher could help students appreciate that not all science is associated with empirical investigation and that science involves creative thinking as, for example, in formulating mental models to explain behaviour (which in some contexts, e.g., here particulate nature of matter, can be shown through kinaesthetic simulation).
    - *Re scientists*. Several teachers referred to students feeling "like real scientists" (T17 *Spinning in space*). Teachers' interpretations of what it means to think and behave like *real* scientists is problematic but Ucar (2011) reported that preservice teachers still held some stereotypical views on graduation. One teacher said. "Faces belittled the resource sheet. Real scientists would not use these" (T9 *All sorts of stuff* S2 Eval). This could have positive or negative effects depending upon how the teacher handled the context of the interchange with their students.
    - *Re appropriate content and concepts in science.* Some teachers reported how their beliefs about appropriate content were found to be quite different to the students:

        > A great lesson. I thought the Volta sheet and timeline activity a bit boring but the children didn't mind and in fact still talk and remember information about Alessandro Volta. Worked really well. (T12 *Electric circuits* S3 Explore L2) [Indicates that 'Science as a Human Endeavour' content can attract students.]

        At other times teachers differed markedly in their views of what was appropriate for their students, for example in *Smooth moves* (Stage 2):

        > I have found the module to be *interesting and thought provoking* to me and the children. (T10G *Smooth moves* italics added)
        >
        > I think the whole of the *concepts involved here are too hard* for students beginning Year 3 and 4. I think they should just be experimenting with the forces and gaining experience and having fun, not expected to complete such closed and complex experiments, tables etc. which made it *boring and confusing*. (T3G *Smooth moves*)

        There were other examples of how beliefs about science content varied. Some teachers felt that learning about solids, liquids and gases did not relate to everyday life (T10 *Material matters*) while others linked it to the students' lunches etc. (T11 *Material matters*).

    - *Re pedagogy in science.* Several issues arose that suggested teachers hold a range of beliefs about what is appropriate pedagogy in primary science. One example was obtaining a balance between hands-on and minds-on science; this created tension for some teachers and was probably more apparent with teachers of younger learners. Two other areas related to trust in 'pedagogy' consistent with constructivist learning causing concern and the role of explicit teaching in science.

The above beliefs, at times, led to teachers either abandoning specific lessons or making (sometimes significant) adaptations to *Primary Connections* lessons. In reporting these contrary views, it must be remembered that other teachers of students in the same Stage reported successful lessons. This emphasises that the teaching context can account for why some teachers reported success while others expressed difficulties. This, however, does not discount that teachers' beliefs about appropriate pedagogy for students can impact on what teachers do in classrooms.

The tension between hands-on activities and scaffolded direction (e.g., discussion and writing) is illustrated in the following extracts:

> Good mixture of discussion (sitting still) and moving (observing, walking, purposeful play, role play) – better balance throughout unit and most importantly, within lesson 4 (4G *On the move* S1) [Lesson 4 was an 'explore' lesson in the final version of this unit.]

> Teacher and students spent too much time playing with the toys, needed to spend more time looking at the 'science' within the activity! (T10 *On the move* Explore L4 [about 'Toys that move']).

On other occasions, teachers expressed concern that directed scaffolding was expected, rather than further hands-on activities, or simply that there was too much discussion anticipated in some lessons:

> The hands-on activity really got the students interested in the topic…BUT There was a lot of discussion and students tended to get bored and restless. (T11 *Smooth moves*)

Getting the balance right is important, while remembering quality science is not simply hands-on tasks (as has been appreciated for many years: "activity by itself is not enough. It is the sense that is made of it that matters" [Driver, 1983, p.48]).

- Teachers' confidence to teach science appears to have been influenced by a range of factors related to *Primary Connections*.

These factors included, firstly, *teaching* the *Primary Connections* units, and secondly, the subsequent *enjoyment* that teachers experienced. This enjoyment was usually a consequence of observing the impact *Primary Connections* had on their students' interest in science and their learning. Access to readily available *science background* material as in *Primary Connections* also appeared to assist confidence, as did the *Primary Connections* professional development 'activities'. Sometimes a few teachers expressed negative feelings about a particular unit; when these feelings were not balanced by more positive feelings in other sections in the unit (which they usually were), then the impact on these teachers' confidence is problematic.

Some extracts that illustrated these assertions are:

- *Positive impact of teaching Primary Connections on confidence*
  Although beliefs about teaching approaches can be difficult to change teaching using the *Primary Connections* framework may change teachers' confidence and the way they think about teaching science:

> This unit (On the move) was easier/less open/more directed ?! than Term 1 with Weather. I think the new weather ideas we worked on in … will make that unit easier to follow. But, *it may be that I am getting more comfortable with the whole idea of teaching science this way* (8G On the move S1, italics added).

- *Teachers' enjoyment in implementing Primary Connections*

When teachers enjoy teaching science then this may increase their 'science teaching self-efficacy' which is a combination of their perceived ability to teach the subject and also that they believe they can impact on students' science outcomes (e.g., see Enochs & Riggs, 1990). For some teachers, science seemed more attractive to teach as with this Early Stage 1 teacher (underlining indicates 'enjoyment'):

> We are particularly impressed with the most recent science units for Early Stage 1 and Stage 3. They have been <u>a dream to teach</u> and share the learning experiences with our classes. (T3G *On the move* ES1)

- *Impact of Primary Connections professional development 'activities' on enjoyment*
  In developing confidence in using new pedagogy or introducing new content, some teachers drew on their professional development experiences (cf. Fittell, 2010a,b)

  > Teachers loved this activity *at workshops* (T13 *All sorts of stuff* S2 italics added: the activity was 'Snap Tear or Stretch' related to properties of materials)

- *Influence of Primary Connections' 'science background' on confidence*
  Many writers have argued that primary teachers' limited science background erodes their confidence to teach science (e.g., Holroyd & Harlen, 1996). Teachers who most encourage inquiry-oriented science are often those with 'intermediate' science knowledge background, not necessarily those with a 'strong' science background (Dobey & Schafer, 1984). *Primary Connections* provides succinct descriptions and explanations of key science ideas related to common alternative conceptions that students and teachers may hold. Teachers reported that it had assisted their confidence to teach science. An example was *Electric circuits* in which eight teachers complemented the value of the 'science background' including it "was very helpful (especially since science is not really my forte!)" (T3G *Electric circuits*).

Other implementation issues detailed in the full report referred to:

I. Support for the relationships that *Primary Connections* provided for addressing literacy outcomes while students were also learning science; and
II. Most teachers' comments indicated that system and school requirements could still be met while implementing *Primary Connections* (this response was positive as *Primary Connections* could be described as having a reform agenda).
III. Some potential barriers to implementing *Primary Connections* were identified. They were: a lack of familiarity with research evidence about student learning; a perceived lack of consideration of pre-requisite skills and knowledge; teachers' limited use of scientific and pedagogical terminology; difficulty in accessing equipment and materials; and inadequate time. Some of these were the concerns of only a couple of teachers, while the last mentioned was referred to most often; however, many of these latter teachers still complimented sections of the units they trialled.

CONCLUSION

A general conclusion that can be drawn from the overall study is that *Primary Connections* has had a very real and positive influence on most (if not all) responding teachers' thinking about the nature of inquiry-oriented and constructivist-based (as in the 5E model) science learning at the primary level. It would appear that these teachers' perceptions have been realised, to varying degrees, in many classrooms. Furthermore, for some teachers, the influence of *Primary Connections* has produced teaching and learning environments that fulfil many criteria associated with high quality science learning. There was, in many of these teachers' responses, a 'passion' for teaching science at the primary level; it 'oozed' through a range of their comments. This overall impression is significant as for teachers to change their pedagogical practice towards innovative science practices such as inquiry-oriented science and use of the 5E learning cycle often takes in excess of a year (Marek, 2009). It is plausible to suggest that the longer-term involvement in the *Primary Connections* program through the trial of one or more units, and the provision of extensive written reflection is, in part, responsible for the impact on some of these teachers.

If, as noted by Carlone et al. (2010), to keep trying to teach in these ways is a "critical resource" for encouraging teachers to persist in teaching curriculum and inquiry-oriented science, then the findings from this study need to especially reach teachers who have made a 'start'. They, and teachers commencing their use of *Primary Connections*, need to see this style of teaching as a journey, not a destination: 'becoming science teachers' is a life-long professional process (Carlone, Haun-Frank & Kimmel, pp. 956, 961). This study simply provides some further signposts on that journey in order to make it even more enjoyable and meaningful for teachers and their students.

This report has raised a number of issues for consideration by those involved with the professional learning (PL) of *Primary Connections* teachers as well as those who develop support materials for *Primary Connections* and, of course, teachers of *Primary Connections*. A series of detailed recommendations are outlined in the final report (an example of a set of findings and recommendations is shown in Figure 1). As the data have limitations some of the recommendation may simply need further (straightforward) investigation to determine if they are being addressed; other recommendations clearly indicate issues that warrant inclusion in PL workshops and possibly support materials.

Figure 1: Example set of findings and recommendations (Inquiry focus)

Findings and Insights

- Overall there was a strong inquiry orientation during the implementation of the Primary Connections units (7.6)
- All students often collected data (evidence) (first hand and from secondary sources) about the world around and were learning actively (physically and usually mentally); all students were reporting/ recording what they observed (7.2 and 7.4)
- When students recorded electronically this seemed to heighten motivation (7.4)
- Students regularly used science inquiry skills, especially observation, prediction, recording and fair testing (7.3, 7.31-7.33)
    - It was less common for teachers to state that some other inquiry skills were used such as classifying, hypothesising (giving reasons for predictions) and evaluating the data they had collected (7.3)
    - Guided investigations (mainly fair testing) were far more common than open investigations (7.33); fair testing usually needs initial scaffolding (7.7)
    - Many students appear to appreciate fair testing on its first use and improve in their approaches to fair testing with experience but it cannot be assumed that this will be similar for all teachers and their classes and across all content areas (7.33, 7.7)
- Assessment of science inquiry skills did occur but it was not regularly mentioned (compared to assessment of conceptual outcomes) (7.5)
- It was not readily apparent that teachers were seeking evidence from students in order to relate observations to their interpretation (7.4)

Teaching with an inquiry emphasis: Recommendations

These recommendations flow from the above 'Inquiry emphasis' findings

To enable teachers to implement *Primary Connections* more effectively the following be considered as foci in professional learning and/or the development of support materials.

- Encourage teachers be alert to the range of science inquiry skills that they are encouraging their students to use; where feasible consider the value of using ICT when using some of these skills (7.3)
- The concept of 'evidence' be explicitly introduced by middle and upper level teachers especially how it connects various components of the investigation process (7.4)
- The value of sharing and discussing with teachers some of the exemplary examples of fair testing and the use of various science inquiry skills in chapter 7 (and section 5.4)
- Indicate feasible ways that teachers can assess science inquiry skills in a summative sense (7.5)

The numbers indicate how the findings and recommendations are derived from the evidence in the preceding sections of the final report.

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Appendix 1: Purposes of the phases in the 5E learning cycle (AAS, 2008)

ENGAGE

Create interest and stimulate curiosity.

Set learning within a meaningful context

Raise questions for inquiry.

Reveal students' ideas and beliefs, compare students' ideas

EXPLORE

Provide experience of the phenomenon or concept.

Explore and inquire into students' questions and test their ideas.

Investigate and solve problems

EXPLAIN

Introduce conceptual tools that can be used to interpret the evidence and construct explanations of the phenomenon.

Construct multi-modal explanations and justify claims in terms of the evidence gathered.

Compare explanations generated by different students/groups.

Consider current scientific explanations.

ELABORATE

Use and apply concepts and explanations in new contexts to test their general applicability.

Reconstruct and extend explanations and understanding using and integrating different modes, such as written language, diagrammatic and graphic modes, and mathematics.

EVALUATE

Provide an opportunity for students to review and reflect on their own learning and new understanding and skills.

Provide evidence for changes to students' understanding, beliefs and skills.

Appendix 2: Learner and teacher roles from personal and social constructivist perspectives, as well as inquiry skill and assessment perspectives (Harlen, 2009)

From a personal constructivist perspective

Learners' roles

- *Learning actively (mentally and physically)*
- *Discussing own and others' ideas*
- *Using ideas to try to understand new events/ phenomena*
- *Reasoning about evidence*
- *Modifying ideas in the light of evidence*
- *Developing 'bigger' ideas from 'smaller' ones*

Teachers' roles

- *Making provisions for the learners' roles and*
- *Finding out learners' ideas and skills by questioning, observing etc.;*
- *Deciding on appropriate action based on learners' existing ideas and skills;*
- *Arranging for group and whole class discussion*

From a discussion, dialogue and argumentation perspective

Learners' roles

- *Explaining their own ideas to others with examples where appropriate*
- *Using language appropriate for explaining scientific phenomena*
- *Listening and responding to others' ideas*
- *Defending their ideas using evidence*

Teachers' roles

- *Modelling skills of using talk productively*
- *Acknowledging pupils' ideas in a way that values them;*
- *Asking for examples to clarify pupils' ideas; and*
- *Expecting pupils to support their claims or ideas with evidence*

From an inquiry perspective

Learners' roles

- Collecting evidence (first hand and from secondary sources) about the world around
- *Using inquiry skills (observation, prediction etc.)*
- *Learning actively (mentally an physically)*
- *Reporting and discussing evidence*
- *Reasoning with others about how different ideas fit the evidences (argumentation);*
- *Reflecting on learning processes and outcomes*

Teachers' roles

- *Making provisions for the learners' roles and:*
- *Arranging for group and whole class discussion;*
- *Encourage the use of inquiry skills through questioning; and*
- *Providing time for reflection on learning*

From a formative use of assessment perspective

Learners' roles

- *Taking responsibility for working towards the goals of particular activities*
- *Agreeing the standards of quality to apply in assessing their work*
- *Participating in self assessment and identifying their next steps*
- *Participating in peer-assessment;*
- *Reflecting on learning processes and outcomes*

Teachers' roles

- *Making provisions for the learners' roles and:*
- *Identifying progression towards both short- and long-term goals of learning*
- *Providing feedback that advises learners on how to improve or move on; and*
- *Using information about learners' progress to regulate teaching*
- *Providing the amount of challenge that promotes learning.*