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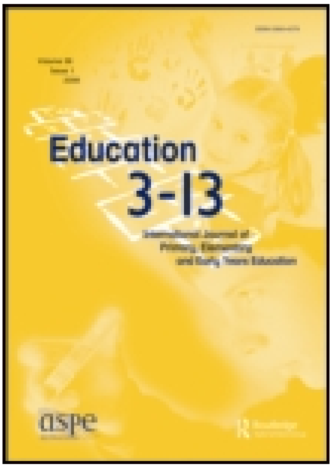

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Formative assessment in primary science

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Formative assessment in primary science

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This action learning study in a year three classroom explored the implementation of five formative assessment principles to assist students' understandings of the scientific topic of liquids and solids. These principles were employed to give students a greater opportunity to express their understanding of the concepts. The study found that the principles of formal assessment worked well in concert with the pedagogical framework of the interactive teaching model.

Keywords: primary science; formative assessment; action learning

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Introduction

This action learning study implemented five formative assessment principles in primary science. Science was chosen due to the impending release of a national primary science curriculum in Australia in 2013 as well as for its hands-on, engaging pedagogy for children at this age.

A primary science curriculum will be released across Australia for the first time in 2013. There has been a primary science and technology curriculum in the state of New South Wales since 1993. The shift to a national curriculum and its attendant regimes of accountability will mean a greater emphasis on the teaching of pure science concepts in the primary classroom across Australia from 2013 onwards. This action learning study attempted to refine the science pedagogy in this classroom through the incorporation of formative assessment principles.

The hands-on, engaging pedagogy of science was an important area to trial the implementation of the principles of formative assessment because of the frustration with the summative assessment task employed in 2010 when this unit was last taught. The results of the pen and paper test administered at the end of the unit did not reflect the type of conversations conducted with the students as they participated enthusiastically in the hands-on activities and whole class discussions. So in 2011, the goal was to capture 'learning in the now' as described in the unit planner.

Formative assessment has become a key goal for educators and educational systems in the last decade. The impetus for this move came from a synthesis of research compiled by Black and Wiliam (1998) on the critical role of formative assessment in student learning. This claim has subsequently been validated by a decade of research findings,

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including a substantive body of evidence uncovered by Hattie's (2009) synthesis of meta-analyses.

Formative assessment has also filtered its way into educational policy in Australia via the national professional teaching standards. A highly accomplished teacher (level 3 of 4) at Standard 5.2 should be able to:

> Select from a range of effective strategies to provide targeted feedback based on informed and timely judgements of each student's current needs in order to progress learning. (Australian Institute for Teaching and School Leadership 2011, 16)

The expected standard raises the bar quite high in terms of formative assessment. It is definitely a stretch target of the fledgling Australian national policy framework. These standards will remain aspirational goals unless teacher professional learning addresses the issue identified by Ofsted in England in 2008, 'Too many teachers still fail to see the connection between accurate and regular assessment and good teaching which leads to learning' (Mansell, James, and The Assessment Reform Group 2009, 21). This study reports on an action learning study in which the authors attempted to make the connection between formative assessment and good teaching.

This article reports on an action learning quest to capture 'learning in the now' through the implementation of formative assessment strategies such as video review, reflective blog postings and the use of teacher questioning. This quest happens in the context of a year three classroom (children aged 8–9) learning the science of the liquid and solid states of matter.

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Literature review

This review of formative assessment begins with a brief investigation of the interactive teaching model (ITM) before exploring the work of formative assessment theorists, including the five formative assessment principles formulated by Dylan Wiliam.

The ITM in primary science originated from the Learning in Science Project (LISP) at the University of Waikato (1979–1989). In its first phase, this project focused on eliciting children's understandings of seminal science and technology concepts such as electric charge, animals and changes of state (Osborne and Freyberg 1985). The approach to science pedagogy by LISP with the development of the ITM anticipated many of the formative assessment principles that have been developed in the two decades since. A key feature of the ITM was the identification of students and teachers' existing conceptions of the science topics covered in the teaching packages. The research team employed one-to-one interviews to achieve this aim. This was scaled up for the classroom to pen and paper surveys that could be administered at the beginning and end of the unit similar to a pre-test, post-test experimental design (Osborne and Freyberg 1985). The authors of the teaching packages were confident enough in their knowledge of students' existing conceptions to be able to design learning activities that would challenge these range of existing views and move them towards the accurate scientific view (Osborne and Freyberg 1985). In summary, the ITM consists of four phases designed to assist students and teachers to access their existing conceptions (preliminary and focus), the challenge phase where students test their ideas against the evidence and an application phase where students employ their new ideas in a range of challenges for these ideas 'to gain in plausibility and usefulness' (Cosgrove and Osborne 1985, 113).

The generative teaching packages developed by the LISP team had the necessary curriculum, assessment and pedagogy to enable student learning in science. This integrated view of pedagogy is sometimes lacking in research that reports the effect sizes of separate strategies that are aligned with formative assessment or feedback but, as Marzano (2007) argues, these strategies are pointless administered in isolation if the teacher does not at first set clear, structured and challenging goals for the students in their class.

There was also a strong emphasis in the ITM on the teacher's use of elicitation questions to access student's existing conceptions. Elicitation questions move the ITM pedagogy into the more complex world of classroom interactions and into one of the deeper formative assessment principles identified by Hume and Coll (2009, 270) 'such as questioning, feedback requiring students to respond to the comments by further work, and peer- and self-assessment'. In contrast, they identified the more shallow strategies to be restricted to 'sharing learning intentions and success criteria, and providing comment-only feedback' (Hume and Coll 2009, 269). Hume and Coll (2009, 270) argue that this regression to 'procedural compliance' in the name of formative assessment by teachers results in 'assessment as learning' rather than 'assessment for learning'. In the same vein, it may be possible for teachers to implement the four phases of the ITM in a mechanical fashion without doing the thinking on your feet required in the classroom as you respond to students' learning. In this sense, knowing what question to ask and when in order to elicit students' understanding is a fundamental element of the ITM that needs to be understood by teachers.

There is support in the research literature for elicitation questioning. Alton-Lee's (2003) best evidence synthesis focusing on quality teaching for diverse students highlights many findings that attest to the power of teacher questioning for elicitation. The synthesis pinpointed the finding that

> Students report not liking these elicitation questions before instruction, but value the activity because it helps them to understand the kinds of issues they need to come to grips with. They report that it helps them focus on the goals for learning from the outset. (Alton-Lee 2003, 91)

Alton-Lee's (2003) synthesis also draws attention to the critical role that students must play in 'the process of question asking and answering, structured self-regulation, critical thinking and sustained thoughtfulness' (90). This finding is important as it positions teacher elicitation questions as being just one part of a classroom environment where students are encouraged to be responsible for and monitor their own learning.

Dylan Wiliam's explication of formative assessment is more holistic than just the application of a few choice strategies suggested by the tenets of evidence-based policy. In his most recent text, he offers the following definition:

> An assessment functions formatively to the extent that evidence about student achievement is elicited, interpreted, and used by teachers, learners, or their peers to make decisions about the next steps in instruction that are likely to be better, or better founded, than the decision they would have made in the absence of that evidence. (Wiliam 2011, 43)

In this definition, Wiliam (2011) makes a clear distinction between an assessment and 'the function that evidence from the assessment actually serves' (43). This distinction is important as it extends the practice of formative assessment beyond the limited confines of the application of a discrete method of assessment. In Wiliam's (2011) view, this expanded conception of formative assessment negates the need for the construction of new labels to describe this process such as 'assessment for learning' or 'feedback'.

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Wiliam describes five key principles that coalesce to achieve the aim of making the teaching ‘adaptive to student needs’. These five principles are taken from an earlier article on which Wiliam was a co-author:

(1) Clarifying, sharing and understanding learning intentions and criteria for success.
(2) Engineering effective classroom discussions, activities and learning tasks that elicit evidence of learning.
(3) Providing feedback that moves learning forward.
(4) Activating learners as instructional resources for one another.
(5) Activating learners as the owners of their own learning (Leahy et al. 2005, 20).

The combination of these five principles constitute a sound theoretical and analytical framework for an action learning study in a classroom that sought to apply ‘theoretically informed ideas about teaching and learning’ (Mercer et al. 2004, 27) to classroom practice within the pedagogical framework of the ITM. This review has linked the principles of the older ITM to more contemporary ideas of formative assessment in an effort to establish a more holistic base from which to build this action learning study.

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Methodology

The practice of action learning originated as a workplace learning strategy to improve productivity in the mining industry, from which it has spread to many other fields of which education is only one (Smith and O’Neill 2003). Action learning requires the teacher to go beyond their individual experience by sharing their knowledge in a systemic, formal process of group discussion and critical reflection, with the goal being career-long improvement in practice. In addition, action learning does not rely on outside programmatic or managerial initiatives to bring about improvements in teacher practice, but situates this responsibility with teachers themselves (Zuber-Skerrit 2002).

Action learning is a subset of the broader methodological field of action research. In this respect, this study was guided by the following principles of action research summarised from Ax and colleagues:

(1) The development and application of professional knowledge in a heuristic spiral, whereby results of one iteration inform the approach to be taken in the next.
(2) Interaction with academic knowledge to provide a theoretical framework in which to take concrete action mindfully.
(3) An understanding of how to study one’s own practice as it intersects with changing classroom circumstances and curricular requirements.
(4) To eschew an isolated individual approach to learning in favour of shared and collaborative knowledge-building.
(5) Understanding the interaction between everyday classroom activities and the desired instrumental and ideological outcomes of the teaching enterprise. (Ax, Ponte, and Brouwer 2008, 56–57).

Each of these principles as they apply to this action learning project is discussed in the next section alongside their corresponding number on the list.

(1) The action learning study emerged from a collaboration between the teacher and teacher educator that began in 2009. The classroom teacher originally

conceptualised the project as an opportunity to learn about pedagogies for primary science from a more experienced teacher educator with research degrees in this area. In reality, it was more like equal partners as the teacher's knowledge of the students balanced the teacher educator's knowledge of science pedagogy. The evaluation of the 2009 teaching informed the 2010 teaching which, in turn, informed the teaching of this unit in 2011. The heuristic spiral has also continued into the fourth successive teaching of this science unit in 2012, the results of which will be published in another article.

(2) This action learning project employed the theoretical framework of formative assessment. This was an effort to lift the theoretical rigour of this study: 'the pursuit of applied, practical educational research need not entail the loss of a theoretical dimension in favour of mere evaluative description' (Mercer et al. 2004, 27). The adoption of a theoretical framework to a classroom-based study such as this can lead to empirical evidence that makes the claims of educational research more robust as well as immediately useful to practitioners. It also disturbs the linearity implied by the term evidence-based practice as the empirical work in classrooms can contribute to a body of practice-based evidence.

(3) The study of the practice of science teaching in this study has occurred at a time when the Federal government in Australia has been going through the preliminary phases of introducing the first national curriculum for the teaching of primary science. Indeed, this was one of the reasons for the study so that the school would have a flying start to the implementation of the national syllabus that will happen a year later in the state of NSW in 2014.

(4) The collaboration in the project spanned the entire teaching cycle. The unit was planned together after an evaluation of the previous unit. Then the unit was taught with each teacher playing an equal part in the lessons. This is one aspect of collaboration that is normally hard to achieve, given the reality of one teacher per classroom but was possible here due to the flexibility of an academic's work timetable.

(5) The final principle of action learning followed was the consideration of the bigger picture in education that this action learning was working towards. In this respect, this investigation of primary science pedagogies highlights the relatively low status of the discipline in the primary school. The importance of scientific methods and concepts to the larger culture warrants a greater focus on the development of these in the primary school. At the very least, this would serve as an antidote to the relentless focus on the basic skills of literacy and numeracy that currently dominates professional learning agendas in the policy and practice of Australian education systems.

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Method

The unit of study was taught to a year three class with 27 students aged 8–9. A similar unit on liquids and solids was taught to a year three class in 2010. The 2010 unit focused on a science outcome from the draft national science curriculum, 'S3SU4 The differences between liquids and solids and how they can change under different conditions'. The pedagogical sequence in 2010 consisted of five science lessons taught every fortnight over a 10-week school term. The sequence involved an introductory lesson with a demonstration of the three states of water as well as concept definition assisted by video materials. The next three lessons were hands-on investigations for the students designed to challenge their existing conceptions. The first investigation was into Oobleck, the non-Newtonian solid that takes its title from the Dr Seuss (1949) book, *Bartholomew and the Oobleck*. The second was making dipped candles and the third making crystals. The final lesson of the sequence was a pen and paper assessment task that examined students' understandings of the concepts taught in the unit.

The pen and paper summative assessment task administered at the end of the unit in 2010 revealed that there were students who could not reproduce the learning on paper that they had demonstrated through their talk in class. The evaluation of the 2010 unit resulted in a search for a method of continuous assessment that might assist the teacher to respond to student learning whilst it was happening. The result of this evaluation led to some reorganisation and changes to the pedagogical sequence in 2011 with the inclusion of strategies based on formative assessment rather than assessment of learning (Wiliam 2011).

The first step in the action learning method for 2011 involved an initial planning meeting where a revision of the unit from 2010 resulted in the inclusion of a focus on formative assessment. This action learning foci was included in the unit plan, 'capturing learning in the "now": flip cameras/blog anecdotes, students choose what to document; group reflection as product'. The teacher and researcher met after each of the four lessons to debrief and discuss student understanding of the concepts. The other form of reflection employed was through email conversations.

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Data analysis

The main form of data collected in this study were videos of small excerpts of the lessons, digital still images of the lessons, students' written reflections of the lessons recorded on the class blog, the annotated unit planner that recorded the teachers' perceptions of the learning events and the record of our email conversations. We attempted to analyse all of these forms of data continuously in the spirit of formative assessment (Mansell, James, and The Assessment Reform Group 2009).

Results

The results of the implementation of the five formative assessment principles are reported here. In doing so, there is an account of the effectiveness of each principle in enabling the elicitation of students' emerging ideas and conceptual development.

Principle 1: clarifying, sharing and understanding learning intentions and criteria for success

The first lesson was designed to share the learning intention of the unit by focusing the students' attention on the concept of the states of matter. This is consistent with the focus phase of the ITM where activities are used in order for students to identify their preconceptions of the scientific concepts.

Four different activities were deployed in the lesson. In the first activity, students were provided with a large variety of images of objects in different states of matter and asked to classify or categorise according to their own ideas without any class discussion as an entry point. The students then shared their ideas and discussed how they chose to classify their objects and which objects were hard to categorise and why. We then introduced the concept of states of matter and classified objects into solids, liquids and gases, using the notebook programme on the interactive whiteboard. A video (Kchinghong 2008) on the behaviour of molecules in liquids, solids and gases was then shown to the students. This video used a very strong analogy of formations of 'dancing lumps' in chocolate to scaffold student understanding of molecular behaviour in different states.

The next part of the focus lesson involved a teacher demonstration where ice cubes were heated in an electric saucepan to change state from solid (ice) to liquid (water) to gas (vapour). The students were asked to identify the energy source that caused the changes in state in the demonstration and to draw and label the process including diagrams of molecular structures. We finished the lesson by completing a worksheet where the students worked in pairs to identify as many examples of liquids, solids and gases that would be found in the human body. The delivery of the key concepts in multiple learning modes as described ensured there was a consistent focus on the learning intentions set for this lesson and the entire unit.

The effectiveness of this focus lesson in directing students' attention was gauged by the reflection activity that followed in the next lesson. Writing in pairs on the classroom blog, students were asked to formulate a question they had in regard to the states of matter. Twenty-two of the 28 questions created focused on the behaviour of molecules, four on the states of matter alone and two questions centred on other topics. The emphasis on molecules in the students' questions may have been due to the impact of the YouTube video on the students' conceptual development where the movement of molecules was represented by the dancing lumps. This prompted one student to ask, 'How many times does a molecule do its dance?'. This question does relate to the concept of changing states but other questions focused on molecules in isolation, 'Do molecules have skeletons inside them?; Do molecules have feelings and can they change?; How many molecules make up the universe and everything in it?'. Two of the twenty-two questions on molecules focused on their behaviour in relation to the states of matter: 'Why do the molecules in gas float around and not stay together?; When the sun shines on molecules why do they get more excited?'. Four of the questions focused directly on states of matter: 'How can energy make things change state?; What is the maximum temperature at which a liquid turns into a gas?; Are all gases created from burning objects?; Why can't all matter exist in all three states?'.

The reflection activity was useful as it provided an insight into students' thinking in relation to the key learning intention of the unit: the differences between liquids and solids and how they can change under different conditions (S3SU4). The students' responses indicated that only six students had focused on the changes of state whilst 20 had become very interested in this new concept of molecules. This focus on the molecules suggests that the video was the most effective learning activity in this lesson and that we had not been effective enough in emphasising the change in the states of matter and the cause of this change.

In summary, the four activities together were not as effective as focus activities on the learning outcome due to the disproportionate impact of the video on students' emerging conceptions. When this was apparent from the analysis of the blog entries, we realised that we would have to redirect students' attention onto the learning outcome in the remaining three lessons.

Principle 2: engineering effective classroom discussions, activities and learning tasks that elicit evidence of learning

To elicit evidence of learning, we employed video collection of student talk and blog entries around these videos. Student responses during the first task revealed that four different pairs of students had developed a good understanding of the changing properties of the Oobleck

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and also the conditions around these changes of state. The properties of this non-Newtonian fluid are called shear thickening, in that the viscosity of the liquid Oobleck increases under stress. In other words, Oobleck behaves like a solid when it is put under stress. In our experiment, the students' hands provided the stress. This was captured in the response from one pair:

> When you apply pressure the molecules slow down and stay closer together. But when you let it go it will transform into a liquid. The molecules will be going faster when you leave them alone but when they are in your hands they become a solid. The heat and the pressure are creating a change of state to occur. (Student, class blog entry, 4 November 2011)

The molecule focus was still evident in the response as it was in the following example:

> It's a solid when it has a force applied to it but is a liquid when it has no force such as when you pour it, it is a liquid. When it behaves like a liquid all the molecules are letting themselves be moved freely but when it behaves like a solid the molecules don't let themselves be moved. (Student, class blog entry, 4 November 2011)

The next blog entry demonstrates a very good understanding of the properties of a non-Newtonian fluid:

> The molecules start moving in different shapes and directions once you start to apply pressure or energy with your hands such as a squishing action. It is a liquid when you just pour food colouring and you don't do anything with it. When you squish the Oobleck it is a solid. It is not a gas it is either a liquid or a solid. It is a solid when you pick it up. (Student, class blog entry, 4 November 2011)

This response also connects the pressure applied to the changing properties of the Oobleck:

> When you apply pressure the molecules slow down and stay closer together. But when you let it go it will transform into a liquid. The molecules will be going faster when you leave them alone but when they are in your hands they become a solid. The heat and the pressure is creating a change of state to occur. (Student, class blog entry, 4 November 2011)

The first four responses cited above demonstrate that these eight students had developed quite a sophisticated understanding of the properties of Oobleck. This was not the same across the class as some of the responses reveal that students were developing their conceptual understanding from a wide variety of environmental stimuli:

> We think the molecules are going crazy then sooner or later the molecules go hypo. We also think that Oobleck is a solid and liquid and might be a gas if you heat it up. We think that Oobleck is just like chocolate because when chocolate is in the sun it melts into a liquid from a solid. So when energy is applied, things change state. (Students, class blog entry, 4 November 2011)

The two students have drawn upon a range of their learning experiences in the unit thus far. Their explanation identifies the changing properties of Oobleck yet they are unable to pin-point exactly what is taking place. Their response prompts us to reposition the Oobleck activity in the learning sequence as it is scheduled too early in the experiential phase of this unit and did actually generate some student confusion in the development of their conceptual understanding. When students are consolidating their emerging concepts of

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what is a solid and a liquid it is probably not good to introduce a new category that behaves both like a solid and a liquid so early on in the sequence of explorations. This is compounded by the cause of this change being pressure rather than the heat that caused the change of state in the focus lesson. In hindsight, it would have been better to do the next lesson that is featured here, on Candles, as the first experiential lesson and position the more challenging investigation involving Oobleck later in the unit. In this case, our evaluation of the student discussion as a principle of formative assessment has resulted in the change of the unit sequence for the next action learning cycle.

In continuation of our strategy to engineer classroom discussion and capture student talk, key elicitation questions and blog reflections were also used in the Candle investigation:

What are the changes of state occurring?

Ten of the 13 responses were able to correctly identify the change of state from the liquid wax to the solid. Here are three such responses:

> Every time you put the wick in the melted wax the wax turns into a liquid because the heat gets colder every time you take it out it gets colder but then the cold water turns it into a full solid object which is a candle. Every time you dip the wick into the melted wax it is a liquid, but when you put it into the cold water it turns into a solid. (Student, class blog entry, 18 November 2011)

> The changes of state that are changing is liquid to a solid. The wet, hot wax sticks onto the wick and when the wick is dipped into the cold water it hardens. (Student, class blog entry, 18 November 2011)

> When the candles are dipped into the liquid wax and then the melted wax turns from liquid to solid, this can only take place if it is dipped into a cold substance. (Student, class blog entry, 18 November 2011)

There were three responses that did not identify the changes of state. Here are two of them:

> The molecules are dancing back and forth with a partner, when we put the wick in the boiling wax the molecules get excited and jumps onto the wick. (Student, class blog entry, 18 November 2011)

> The things that are occurring are the wax that is burning the wick and the wick is burning so the hot wax is taking over because the wax is hotter than the wick so it burns it. When you dip the wick in the hot wax it drips from the wick then after you dipped it in the frosty cold water it makes a blob when you take it out. (Student, class blog entry, 18 November 2011)

The first incorrect response focuses more on the behaviour of the molecules that was covered by the next question.

What are the molecules in the wax doing and why?

There were three responses from nine attempts at this question that could be regarded as conforming to the scientific view, albeit expressed in their own language:

> The molecules are going really fast when you put it into the wax but then the water basically pressed the pause button and made everything slow down. (Student, class blog entry, 18 November 2011)

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> The molecules that form liquid are disorganised, and therefore, they go crazy. The cold water turns the liquid molecules into solid molecules, which have more magnetic force and slows the molecules down, which eventually, turns into a solid. (Student, class blog entry, 18 November 2011)

There were six incorrect responses from nine attempts. The following response seems to conflate the properties of the state with the behaviour of the molecules within, although it could be argued that they are linking the liquid state to a more random pattern of molecules:

> The things that are occurring would be the wick being dipped into the bowl of melted wax then into the freezing cold water. The molecules would be going crazy in the hot wax but then when they get dipped into the cold water they get pulled out and freeze so that they concentrate. The thing making the changes of state occur would be the wax and water. (Students, class blog entry, 18 November 2011)

The next two incorrect responses reflect the personification of the molecules that was encouraged by the video of the dancing molecules that we showed in the first focus lesson:

> The molecules are dancing back and front with a partner when you melt the wax it turns liquid wax and when you dip the wick inside the liquid wax and the cold water the molecules get turn into a solid. (Students, class blog entry, 18 November 2011)

> When you dip it in the hot wax the molecules are saying to each other look there is something to hang on to so they hang on to it. When you dip it in the frosty water they are so cold that they stick to it and stay there. (Students, class blog entry, 18 November 2011)

What is causing the changes of state to occur?

There were three responses to the last question:

> The thing making the changes of state occur would be the wax and water. (Student, class blog entry, 18 November 2011)

> The cold water and hot wax. (Student, class blog entry, 18 November 2011)

> Every time you dip the wick into the melted wax it is a liquid, but when you put it into the cold water it turns into a solid. (Students, class blog entry, 18 November 2011)

In our analysis of this data around student talk 'in the now', we were able to see that the initial video content of the dancing molecules was being widely used by students to provide a conceptual thinking scaffold around their understanding of changes of state. This was especially the case in the form of the analogy of the dancing molecules – where the students' conceptual explanations continued to focus on the behaviour of molecules in their different states rather than what was actually causing them to change state. This enabled us to refocus the learning experiences with elicitation questions and conversations away from the molecular behaviour and instead use this to focus student thinking around the energy forms and transfers taking place to bring about the changes of state.

Principle 3: providing feedback that moves learning forward

The provision of feedback to move learning forward was evident in the predict, observe and explain sequence employed in the lessons (NSW Board of Studies 2012). Elicitation

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questions were planned and used in each part of the sequence as demonstrated through the bottle, balloon and bicarbonate investigation.

We began the lesson by asking the students to predict what would happen to the balloon on the top of the plastic bottle when we mixed the bicarbonate of soda with the vinegar in one bottle as the experiment and with water in the other as the control. Some students hypothesised a reaction for both solutions. There was also a hypothesis that the vinegar would cause a stronger reaction than the water. This hypothesis was explored through discussion by asking the simple elicitation question, that's interesting, why do you think that? The student's explanation was that vinegar would cause a stronger reaction because it was manufactured rather than naturally occurring. There was also excited speculation about explosions as well as predictions that the solution would 'fizz and create bubbles' (Unit planner annotation, 29 November 2011).

Students were put into pairs for the experiment with one student assigned the bicarb' and vinegar and the other student the bicarb' and water. There was little need for elicitation questions at this stage of the sequence as the balloon was the evidence in this experiment as elated students watched the balloon inflate if they had the vinegar and disappointed students saw no reaction if they had the water.

There were many opportunities to provide feedback to move learning forward in the explaination part of the lesson. Obviously a key question here was *what made the balloon inflate?* but we needed to begin with what we had already covered on states of matter so we asked, *can you identify the three states of matter in your experiment?* The solid and liquid in the form of the bicarb' and vinegar/water were easily identified by the students but the connection to the gas in the balloon had to be made by asking the question, *what is in the balloon?* As a result of this elicitation some students were able to identify the gas as another state of matter.

In summary, the predict, observe and explain sequence gave this lesson a clear structure from which it was possible to plan and employ elicitation questions that might move learning forward. The act of planning questions before the lesson forces the teacher to think about the kind of developing ideas that might emerge from students as a result of the scientific activities.

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Principle 4: activating learners as instructional resources for one another

Our focus on formative assessment within the ITM and experiential activities to capture learning in the now, positioned student interactions, collaboration and talk as integral meaning-making processes involved in the development of students' conceptual understanding. The blog entries and video content captured how crucial learner interactions were as they predicted, observed and explained their scientific investigations and thinking in these learning experiences. Often, student talk and blog postings enabled them to 'hitchhike' their understandings as a result of response, analysis and elaboration from others comments and ideas.

The focused student talk enabled by elicitation questions through the ITM and predict-observe-explain frameworks activated purposeful opportunities for students meta-cognitive processes as encouraged by 'the process of question asking and answering, structured self-regulation, critical thinking and sustained thoughtfulness' around the key scientific concepts (Alton-Lee 2003, 90). Furthermore, the inclusion of video content of the students captured learning in real time in the blog page (the Oobleck experiment) enabled students to reconnect, reflect and then use other student responses to clarify and communicate their understanding.

Finally, more traditional forms of student-sharing were employed in the lessons. Two examples of these were the use of 'talking triangles' and 'shoulder buddies' where students were asked to discuss their ideas in either groups of three (hence triangles) or in pairs (buddies). The buddy discussion was used extensively in the predict, observe and explain aspects of the lesson of the lesson where the focus was on chemical rather than physical change (bottle, balloon and bicarbonate experiment). In the prediction section, students were shown the materials for the experiment and asked to discuss what they think would happen with their partner. In the observe phase of the lesson, they needed to discuss the different results they and their partner observed as the bicarbonate was mixed with the vinegar or water. Finally, the students discussed their explanations for their results with their partner before sharing their thoughts with the whole class in a plenary discussion. The depiction of these discussions can seem rather commonplace in comparison to the earlier examples cited of students making blog posts responding to live videos online. In actual fact, these structured collaborative discussions were the dynamo that drove conceptual learning in the classroom.

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Principle 5: activating learners as the owners of their own learning

The ITM employed in our action learning ensured that working in tandem with student talk and collaboration was a continuous thread of individual conceptual understanding afforded by the teacher focus on formative assessment principles, in that there was a consistent lineage made between student preconceptions (entry into unit), changing conceptions (throughout unit experiences and interactions) and the development of concrete conceptual understanding (outcomes of teaching and learning experiences).

Evidence for the successful application of this principle lies in the difference between the questions the students asked after the first lesson and the integrated responses to the Oobleck experiment captured in the figure above. To recap, 22 of the 28 questions asked by the students at the end of the first lesson focused on the behaviour of molecules, four on the states of matter alone and two questions centred on other topics. We argue that this exercise allowed students to identify (or own) their current understanding of states of matter. It also allowed us as teachers to realise that we needed to link the behaviour of molecules to the physical state of the material under observation as well as direction of attention to the energy that was the cause of the change such as heat or pressure.

At the end of the second lesson of the sequence on Oobleck, students were able to do this: 'When you apply pressure the molecules slow down and stay closer together' (my3lk blog posting, 4 November 2011). This ownership of the students' new learning was also expressed in this post:

> The molecules start moving in different shapes and directions once you start to apply pressure or energy with your hands such as a squishing action. It is a liquid when you just pour food coloring and you don't do anything with it. When you squish the Oobleck it is a solid. (lh3lk blog post, 4 November 2011)

Activating learners as the owners of their own learning through the development of their questions or through blog posts informed the next steps for teaching and learning for the teachers. It also enabled the students to identify where their current understandings at the beginning of the unit and to revisit this conceptual thread throughout the learning cycle. This fifth principle also demonstrates the convergence between the ITM and the principles of formative assessment as both models emphasise the importance of constantly accessing students' understanding of the focus concept both for the benefit of the teacher who is guiding the learner and the students who are learning a new concept in science.

Conclusion

The implications of this study focus on setting clear and challenging goals, the need to constantly monitor what students are learning from their activities and, in response, adopting a flexible programme which remains focused on the formative assessment of the focus concept.

The analysis of our teaching suggests that we need to set clear and challenging goals for the class as specified in principle one of formative assessment (Leahy et al. 2005). As Marzano (2007) acknowledges, 'without clear goals it might be difficult to provide effective feedback' (12). There were clear goals for the introductory lesson as well as lesson three on the dipped candles. Lessons two and four introduced two new concepts that did not contribute to the students' understanding of the big idea for this unit. It is interesting to note that in the latest draft of the NSW interpretation of the national primary syllabus, the knowledge and understanding outcome ST2-12NM for Stage 2 (years 3–4) is 'identifies that adding or removing heat causes a change of state between solids and liquids' (NSW Board of Studies 2012, 48). If future units in this topic are refined to meet this outcome, then the aim of establishing clear goals and providing feedback on these goals to students in each lesson rather than just two might be achieved.

The final implication from the study relates to all five principles of formative assessment (Leahy et al. 2005). This implication focuses on 'the need to constantly monitor what students are or are not learning from their activities and to respond accordingly' (Nuthall 2007, 104). With this in mind, there are two actions that will guide the next phase of action learning. First, we will apply the five principles of formative assessment to evaluate each lesson after it is taught and use this process to inform changes in the learning intentions and pedagogy of the next lesson. Second, we need to adjust our pedagogical repertoire to include strategies where we gather feedback from the students in relation to the learning intentions for each lesson.

This challenge to embed formative assessment in pedagogy is not an idiosyncratic one for us as there are claims that it applies to teachers collectively, as 'it may challenge them to change what they do, how they think about learning and teaching, and the way in which they relate to their pupils' (Mansell, James, and The Assessment Reform Group 2009, 11). There is a tendency in the teaching of hands-on science lessons to expend energy setting up the activity or 'experiment' and then sitting back and breathing a sigh of relief when nothing goes wrong. This may detract the teacher's ability to monitor students' learning.

The challenge is now to develop this part of our pedagogy in the next cycle through modifications of the instructional core (City et al. 2011) that is made up of content, teacher pedagogy and student learning. This holistic approach to systematic change in our practice in the classroom has a greater chance to have an impact on student learning in primary science. In this endeavour, the ITM provides an ideal framework to prepare and sequence suitable content, influence teacher's pedagogy and elicit students' conceptions.

This study has revealed the potential of the ITM to act as a suitable pedagogical framework in which to monitor students' conceptual development using the five principles of formative assessment. The principles of assessment operating in concert with the pedagogical structure of the ITM provides the rigour with which to measure and evaluate student achievement in rich learning experiences in primary science.

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