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An investigation of the effects of discussion-based questioning activities on year 7 science students' self-perception and engagement

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Abstract

This action research intervention investigates the impact of using discussion based around key questions on the conceptualisation of new ideas on chemical reactions in Year 7. The wider impact on student engagement and self-perception is also considered. This study found that questions acted as a good method of scaffolding and supporting productive and genuine scientific discussion between students as well as the 'minds-on' element to practical work. Questioning and discussion-based activities can be successfully used to scaffold learning of chemical reactions. However, this study also recognises that other methods of teaching and learning should be implemented in the classroom to fully support the conceptualisation of new scientific ideas. Discussion-based questioning could improve students' perceptions of themselves as learners, particularly males who already have low academic self-perception. Students showed an improvement in their perceived general ability, verbal ability and fluency and access to use of vocabulary in problem solving.

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Introduction

Both teacher and student talk have significant roles in almost any classroom, making it challenging to imagine a classroom without any dialogue. In particular, classroom discussion and questioning have been identified as having a substantial, yet under-recognised part in the conceptualisation of new scientific ideas (Mortimer & Scott, 2003; Scott & Ametller, 2007).

Studying chemical reactions at Key Stage Three (KS3) introduces students to new concepts that are likely to have tension with their current ideas. Students are expected to apply abstract concepts of atomic theory to conceptualise new ideas of atom rearrangement during chemical reactions, requiring students to work with ideas about entities that they cannot physically see. The language demand of the topic is also significant, with a range of unfamiliar vocabulary including terms such as effervescence, combustion and reactants plus the names and formulas of chemicals.

This study focuses on the impact of using classroom dialogue and questioning to promote meaning making and conceptualisation of scientific ideas to Year 7 students studying chemical reactions. This study also considers the broader influence of discussion and questioning by investigating the impact on student self-perception and engagement.

Literature Review

In this section I will review some of the existing literature looking at the key topics: importance of talk to learning science; approaches to classroom discussion and questioning to scaffold learning; student engagement and student self-perception.

Importance of talk to learning science

In recent years the field of education has become increasingly interested in how classroom talk develops scientific meaning in children (Scott, Mortimer, & Aguiar, 2006). A traditional and ineffective approach to science teaching stems from the premise that a teacher is a possessor of knowledge which is then transmitted to students in the form of an authoritative and teacher-led monologue (McMahon, 2012). In contrast, Barnes, Britton and Rosen (1969) describe knowledge as an entity that is shared through a model of interpretation; the teacher presents a new scientific idea which is individually interpreted by each student, whose learning is then subsequently gauged by the teacher. In addition, Yip (2004) proposes that effective learning of science often requires a conceptual change; students construct scientific meaning by combining new ideas with ideas they already hold as opposed to being the recipient of a delivery of scientific knowledge.

Mortimer and Scott (2003) acknowledge that science teaching has advanced greatly from traditional teacher-focused monologues and it is now largely recognised that careful orchestration of classroom-based dialogue can have a positive influence on student learning through the construction of meaningful scientific knowledge. Modern day science lessons now follow more student-centred approaches; however, Mortimer and Scott (2003) propose that many schemes of work wrongly focus on the activities students engage in during a lesson, such as experiments and creative tasks. Wellington and Osborne (2001) argue that science is often wrongly portrayed as a solely practical subject. Scientific language as well as the 'language of secondary education' can present barriers to student learning and understanding. However, many teachers fail to see how essential language is to science; as a consequence classroom talk and discussion in science is significantly neglected and the importance of it to making meaning in science is not rightfully recognised (Newton, Driver, & Osborne, 1999; Wellington & Osborne, 2001).

The premise that children need to talk about science in order to make meaning from it is in line with Vygotsky's sociocultural approach to learning (Mortimer & Scott, 2003). Vygotsky's approach supports that learning requires a personal internalisation step gained from social rehearsal between individuals (Scott, 1998). This supports the idea that knowledge is not something physical that can be transmitted from one owner to the other and recognises learning as a multifaceted process. In science in particular there is tension between scientific ideas presented in the classroom and the everyday ideas used elsewhere. Students must internalise new ideas presented to them in a social context by combining them with the ideas they already have (Mortimer & Scott, 2003; Löfgren, Schoultz, Hultman, & Björklund, 2013).

To comprehend a new idea, students must be given the chance to talk about it (Wellington & Osborne, 2001). Talk is described as the most 'persuasive and powerful pedagogy' to permit the conceptual change between what a student is yet to understand and what they already understand (Alexander, 2008). Talk is important to this internalisation step as it allows students to engage with the ideas they are trying to conceptualise. To successfully talk about science, the speaker must have an understanding of the meaning of scientific words and how to use them in appropriate manner. In addition to the teacher using talk to introduce, explain and develop new ideas, talk can allow students to construct and justify arguments, discuss evidence, clarify pre-requisites and link new and existing ideas (Wellington & Osborne, 2001).

Talk also promotes cognitive change by allowing students to clarify and rehearse connections between thoughts and spoken word (Flitton & Warwick, 2013). Thoughts and language are described as having a cooperative relationship; therefore, to be able to talk about an idea, for example through argument or justification as described above, shows you have understanding of the language (Wellington & Osborne, 2001; Flitton & Warwick, 2013).

Importantly, it is emphasised that in most cases students will need assistance to talk about science; handing the responsibility of an interactive, scientific dialogue to students and expecting them to engage in worthwhile and productive talk, is largely unrealistic (Wellington & Osborne, 2001). Independent groups of students will often find it difficult and rarely engage in a genuine scientific discussion unless prompted to do so by the teacher (Newton et al., 1999; Gillies, 2016). This highlights the role of the teacher to scaffold discussion activities that enable students to take part in quality classroom talk that supports meaning making. The role of the teacher and talk in this internalisation can be explained by the zone of proximal development (ZPD); a level of work or achievement that a child can do with appropriate support (Scott, 1998). Teachers can provide this support by creating and scaffolding classroom discussion opportunities to allow the social and cognitive meaning making step to take place (Alexander, 2008).

Approaches to classroom discussion and questioning

Scott et al. (2006) explored discursive classroom interactions to develop six teaching purposes of classroom dialogue used for making scientific meaning (Table 1). In addition, Mortimer and Scott (2003) describe two dimensions of communicative approach that can be adopted during a teacher-led discussion. The authoritative-dialogic dimension defines how the teacher presents scientifically accepted ideas and acknowledges alternate ideas. Whereas the interactive-non-interactive dimension defines how a teacher interacts with his/her students during a classroom discussion. A combination of these two dimensions as described by Scott et al. (2006) is summarised in Table 2. It provides a four-part framework for describing and categorising classroom discussion that is well adopted in the literature.

Yip (2004) describes how an authoritative approach to science teaching in Japan leads to students who are competent in factual recall but have poor conceptual understanding of scientific principles. Students perform well on recall-style examination questions but fail at problem solving questions which require true scientific understanding and application of knowledge. McMahon (2012) used the four-part framework described to analyse the teacher's chosen communicative approach according to different teaching purposes. It was concluded that a dialogic approach to science teaching supported student understanding and meaning making. The support was more profound when higher cognitive thoughts were applied to the dialogic discussion, such as exploration, comparison and development of ideas.

Scott et al. (2006) acknowledges the tension between authoritative and dialogic classroom discussion in the classroom. A correct balance of the communicative approaches should be used to structure effective learning and meaning making (Scott et al., 2006). Ultimately, the teacher has the responsibility of selecting an appropriate communicative approach according to the nature of the learning that he/she intends (McMahon, 2012; Tan & Wong, 2012).

1	Opening up the problem.
2	Exploring and probing student's views.
3	Introducing and developing the scientific story.
4	Guiding students to work with scientific ideas and supporting internalisation.
5	Guiding students to apply, and expand on the use of, the scientific view and handing over responsibility of its use.
6	Maintaining the development of the scientific story.

Table 1: The six teaching purposes of classroom dialogue

[Taken from Mortimer and Scott (2003, p.29) six teaching purposes]

Dimension	Interactive	Non-interactive
Dialogic	**Interactive-dialogic:** Discussion between teacher and students is used to explore many scientific ideas and points of view. **Dialogic questioning:** Open-style questions invite students to respond with answers that might explore alternate ideas or student pre-requisites. The end-point of the discussion is not fixed. Therefore, the teacher must orchestrate the discussion based on student responses and the direction she chooses to move in.	**Non-interactive-dialogic:** The teacher explores and evaluates many scientific ideas in a lecture-style presentation.
Authoritative	**Interactive-authoritative:** Discussion between teacher and student focuses on one specific scientific idea defined by the teacher. **Authoritative questioning**: A teacher will progress through a speech which incorporates a question and answer routine which will lead to a defined end point. Questions are typically closed and require short, factual recall style answers.	**Interactive-authoritative:** One specific scientific idea is presented by the teacher in a lecture-style presentation.

Table 2: Four communicative approaches of classroom dialogue

with dialogic and authoritative questioning styles described

[Table adapted from Mortimer and Scott (2003, p.35)]

Using questioning and discussion to support learning

Teacher-led questioning has long been recognised as an important part of classroom dialogue and student learning (Wellington & Osborne, 2001). Traditionally, teachers' questions were seen and used as a means of eliciting what students know (van Zee & Minstrell, 1997; Chin, 2006).

However, akin to classroom talk, questions form a powerful tool to assist students in transitioning through conceptual change; constructing new knowledge by combining what they already know with the new ideas presented to them. Questioning can be used to prompt debate, provoke exploration and require explanation of ideas. These things play important roles in making meaning in science (Wellington and Osborne, 2001).

Yang (2006) considers that teachers' questions are 'the most powerful device to lead, extend and control communication in the classroom'. However, the literature also highlights that not all teacher-led questioning activities are beneficial towards student learning (Wellington & Osborne, 2001; Mortimer & Scott, 2003; Alexander, 2008) and that a shift in the style and methods of questioning is needed to better benefit student learning and meaning making.

The authoritative-interactive dimension of communicative approach can also be applied to classroom questioning (Mortimer & Scott, 2008) (Table 2). An authoritative questioning dialogue is typically characterised by low-order questions (Yip, 2004) and can be modelled by the triadic, initiation-response-evaluation (IRE) pattern of interaction (Wellington & Osborne, 2001). The teacher leads the class through a planned 'recitation script', asking a series of leading and closed questions (the initiation) to reach a pre-determined end-point (Alexander, 2008). Students' responses are evaluated by the teacher who decides what is correct or incorrect. Therefore, there is little freedom to redirect the discussion or explore ideas which could be important for conceptual change and meaning making (Yip, 2004).

In contrast, dialogic questions invite students to respond with answers that might explore alternate ideas or student pre-requisites. These higher-order questions demand deeper cognition, including comparison, analysis, explanation and evaluation (Bloom, 1956). Teachers respond to incorrect responses with extensions aimed at probing the student for further elaboration or thinking, described by van Zee and Minstrell (1997, p.228) as the 'reflective toss'. The end-point of the discussion is not fixed; the teacher must orchestrate the discussion based on student responses, which may be correct or incorrect, organising a clear progression in the conceptualisation of scientific ideas and meaning making.

The quality of students' responses in relation to questioning approaches has been explored (Van Booven, 2015). Teacher questions and feedback were analysed and classified as dialogic or authoritative. Student responses to different questions were then coded according to the cognitive processes involved in their reply, such as factual recall or higher cognitive processes (Bloom, 1956). Typically, dialogic questioning was more supportive of learning and meaning making than authoritative questioning (Van Booven, 2015). Students' responses to authoritative questioning were primarily recall and demonstrated limited scientific understanding. In contrast, students demonstrated multiple higher cognitive processes in response to dialogic questioning.

Analysis of a third type of questioning characterised by an opening closed-style question, which was then opened up by further extension-style questions, also received meaningful responses which required higher order thinking. Therefore, in agreement with Scott et al., (2006) a tension between authoritative and dialogic questioning styles is acknowledged. Van Booven (2015) suggests that a well-orchestrated medium between the questioning styles could achieve higher cognitive thought processes and benefit student learning and meaning making. Black and Harrison (2004) support that closed-style questioning still have a role to play in the science classroom as a useful way for teachers to confirm students' knowledge and to become accustomed to using the language of science.

Black and Harrison (2004) also acknowledge that different questioning strategies and styles can be adopted for different teaching purposes. Yip (2004) highlights that a particular repertoire of teacher questioning can be used to guide and scaffold a student through that conceptual change. Whilst Kawalkar and Vijapurkar (2013) describe some reasons for why teachers ask questions beyond the classic idea of testing knowledge. These include: generating ideas; exploring pre-requisites or setting the stage; probing ideas further; refining concepts or explanations and guiding the class towards accepting a scientific concept.

Student engagement and self-perception

A student's engagement in schooling is recognised as being a significant contributor to their current and future success (Skinner, Furrer, Marchand, & Kindermann, 2008). Higher levels of engagement in academic studies correlate with: success in short and long-term academic careers; higher attendance; higher attainment in tests; completion of formal schooling and success beyond secondary education.

Goldspink and Foster (2013) describe how there is a widespread concern regarding the engagement of students in school and learning. Research shows that engagement declines throughout a child's time in formal schooling (Skinner et al., 2008; Lietaert, Roorda, Laevers, Verschueren, & De Fraine, 2015; Peetsma & Van der Veen, 2015). This decline is also recognised as being more severe in males (Lietaert et al., 2015); and a significant point where engagement drops is the transitional point between primary and secondary education (Peetsma & Van der Veen, 2015; Virtanen, Lerkkanen, Poikkeus, & Kuorelahti, 2015). Importantly, engagement is not presumed to be a fixed behaviour trait (Fredricks, Blumenfeld, & Paris, 2004). Engagement can vary in both time-scale and intensity and be changed with different approaches to pedagogy, classroom environment and social approaches (Fredricks et al., 2004).

Student engagement can be defined as an individual's interest and involvement in their academic education and their willingness to participate in learning activities. Mortimer and Scott (2003) describe how students can display four responses to a learning opportunity: rejection; passive engagement; active engagement; and taking further initiative. Engagement can be further defined under three main indicators: behavioural, emotional and cognitive engagement (Fredricks et al., 2004). Behavioural engagement describes the premise of student participation. For example, exhibiting suitable behaviour for learning; demonstrating positive conduct; being on-task and not being disruptive (Goldspink & Foster, 2013; Clarence Ng, 2014). In contrast to behavioural engagement, the emotional and cognitive dimensions of engagement go deeper than a student simply participating in learning. Emotional engagement is described by a student's emotions towards the learning activities and requires some form of emotional commitment or investment. A student who is emotionally engaged will generally react positively to learning activities by demonstrating interest, enjoyment, enthusiasm and willingness. Cognitive engagement is described by (Fredricks et al., 2004) as an investment in learning. This dimension encompasses that a child who is cognitively engaged will demonstrate much more than behavioural effort and just doing the work. They will approach learning tasks with thoughtfulness and demonstrate the necessary focus and effort to comprehend the ideas presented in the lesson (Fredricks et al., 2004); this might also involve perseverance, problem-solving or taking the initiative to search for additional information (Goldspink & Foster, 2013).

Raufelder, Sahabandu, Martinez and Escobar (2015) recognise that a decline in motivation and engagement also correlates with a decline in student self-perception. Burden (1998) defines self-perception as a multifaceted concept relating to a child's view of their academic self-concept, self-belief and self-worth. Individuals will hold certain judgements about their own ability and capability to perform at certain levels and Burden (2010) highlights the importance of these judgments to students' engagement and motivation in schooling. Furthermore a student's motivation and engagement is now recognised as being significantly important to academic success, perhaps more so than general intellect (Norgate, Osborne, & Warhurst, 2013).

A reliable and certified measure of student self-perception, the Myself as a Learner Scale (MALS), has been developed and well-tested in the literature. The scale was adopted in a study to investigate if there was a decline in student self-perception during the transfer of children into and through secondary education. In line with a drop in engagement, results showed that there was a significant decline in student self-perception as measured by MALS as students entered the first year of secondary education (Norgate et al., 2013).

Methodology

An outline and supporting rationale of the methodological approaches used throughout this study are described in this section. This study and the adopted methods aimed to investigate the following research questions:

- Can pupil discussion centred on key questions be used to scaffold learning of chemical reactions to Year 7?
- Do discussion-based questioning activities improve student engagement in the learning of chemical reactions?
- Do learning activities with a focus on pupil discussion around key questions change students' perceptions of themselves as learners?

School contextual information

This intervention was conducted in a mixed-sex, 11-18 academy in Norfolk. The academy has approximately 1200 students on-roll. The academy's catchment area serves the local town. In general, most students come from households with a low socioeconomic background and the school has a higher than average number of students with English as an additional language (EAL).

The target class for this study was a Year 7 mixed-ability group (7N) containing 21 students (11 males and 10 females). At the beginning of KS3 a baseline assessment was used to distribute students into mixed-ability classes. The assessment used the old National Curriculum levels, and scores for 7N ranged between a level 2c and a level 4a. In the class there are four students who have EAL and seven students identified as having Special Educational Needs (SEN), including one with an autistic spectrum disorder (ASD).

Ethics

This study, including the intervention and subsequent data collection followed the ethical guidelines set out by the British Educational Research Association (BERA) (2011). The Faculty of Education's Ethics Forms, which outlined the nature of the intervention, were signed by the Biology subject lead and the school-based professional tutor. The nature of the intervention (questioning and discussion-based activities) was explained to the class and all students were assured that it would not be detrimental to their learning. Parents/guardians of students were provided with an information letter which contained a contact number and a concern form which could be returned if they wished for their child to not participate. No letters were returned with any concerns. Students, teachers and support staff were informed prior to any audio recordings. All names have been subsequently anonymised.

Overall design

Action research

This study aimed to follow a school-based action research procedure to alter the arrangement of classroom dialogue and questioning in support of student learning and engagement. In the context of education, action research involves an educational practitioner applying a reflective approach to respond to a school-based problem (Wilson, 2013). A practitioner engaged in action research will engage in a cyclical process which progresses through four main stages: reflection, planning, action and observation (Grace, Rietdijk, Garrett, & Griffiths, 2015).

The initial stage involves a practitioner reflecting on their classroom environment to identify a particular problem. Subsequently, the second and third stages require the practitioner to respectively plan and implement an intervention which aims to address the identified problem. The final stage entails data collection and observations of the outcomes of the intervention. After progressing through the four stages, a practitioner will then enter a second cycle, whereby the initial stage of reflection is prompted from findings from the preceding cycle which leads to further planning of the next step of intervention; this defines the cyclical nature of action research (Wilson, 2013).

Pre-intervention assessment and rationale

Initial reflections on observation notes identified my questioning as requiring improvement. In addition, the KS3 scheme of work including the course text book and lesson plans focussed strongly on student activities. For example, writing or comprehension-based tasks, creative activities and practical suggestions; a pitfall of modern science teaching recognised by Mortimer and Scott (2003).

Prior to the intervention, class 7N were observed across four 50-minute lessons with their normal science teacher. Initially, overall student engagement was observed and coded under behavioural, emotional and cognitive engagement. In addition, audio recordings of the teacher-directed classroom dialogue and questioning were coded under two categories: dialogue (authoritative/dialogic and non-interactive/interactive dimensions) and questioning style (closed/open) as informed by the literature (see Table 2). Initial coding results identified that the primary form of dialogue adopted by the class teacher was authoritative-interactive characterised by closed, factual recall-style questions and learning activities focussed on writing and work from the text book. Two transcribed dialogues taken from audio recording during a pre-intervention lesson with 7N are shown below. The dialogue is interactive-authoritative with both teacher and student taking part to consider one point of view. Dialogue is opened by closed-style teacher questions, which requires specific one word responses. Student responses are followed by teacher evaluation or further question to reach the specific answer the teacher is looking for.

Dialogue 1

Teacher: What do we call something that does dissolve in water?
Student: I don't know.
Teacher: If something that doesn't dissolve in water is insoluble (emphasises insoluble), what is something that dissolve in water? (Pauses for reply) It begins with an S.
Student: Soluble.

Dialogue 2

Teacher: This is acting as a catalyst. What's a catalyst? (Pauses for reply) Usain Bolt is good at this. What does Usain Bolt do?

Student A: Running.

Teacher: What's another word for running?

Student B: Sprinting?

Teacher: Another word for sprint! It beings with an S.

Student B: Speed?

Teacher: Good. Speeds up the reaction.

In addition, although behavioural engagement was generally good, few students showed true emotional and cognitive engagement with their work. Therefore, the classroom problem identified was the style of dialogue and questioning used to construct scientific understanding and promote learning and engagement.

Action research was adopted as the methodological approach in this study. An intervention was planned to cover six 50-minute lessons. The intervention aimed to shift from activities focused around practicals, writing and text book comprehension and introduce a new style of dialogue and questioning to improve student engagement, self-perception and benefit learning. Students in class 7N were initially assessed using a questionnaire and survey to gauge their self-perception and attitudes towards science and questioning. Students also completed a concept map to assess their current knowledge. The intervention used various methods of questioning to scaffold student learning and support conceptualisation of the scientific ideas in the 'Simple Chemical Reactions' topic in the KS3 scheme of work. Student engagement was tracked using student questionnaires and observational data. Various methods of assessments, including an end of unit test and a repeat of the concept map were used to measure student learning. At the post-intervention stage students completed the same questionnaire, survey and an interview with a specific focus group was performed to assess if student self-perception, engagement or attitudes to science had changed.

The six lesson sequence represented one cycle of action research. To truly be action research, the reflections taken from this study would then be used to perform further planning to perform a second intervention (Wilson, 2013).

The intervention

The ‘Simple Chemical Reactions’ topic contained four sub topics: observing chemical change; atoms and molecules in chemical reactions; testing gases; and writing chemical equations. Each lesson in the sequence included at least two question-based activities which were largely focussed around small-group or paired student discussion. The literature was consulted to apply a list of six teaching purposes (Table 3) to the different questions-based activities; their overarching purposes were to act as a scaffold to support student conceptualisation, internalisation and meaning making of scientific ideas (Mortimer & Scott, 2003; Yip, 2004; Kawalkar & Vijapurkar, 2013). The questions also served as a method of scaffolding and organising meaningful student-led discussions.

1	To present or open up a problem; setting the stage.
2	Exploring and eliciting student ideas and prerequisites,
3	To introduce or develop a scientific story,
4	Guiding students to work with scientific concept or idea and support their internalisation; refining conceptions and explanations.
5	Guiding students to apply the scientific view in other contexts; hand over responsibility of its use.
6	To hand over responsibility to students and guide application of the scientific ideas.

Table 3: A repertoire of six question types identified from the literature as supporting conceptualisation of scientific ideas [Adapted from Mortimer and Scott (2003); Kawalkar and Vijapurkar (2013)]

Questioning activities focused largely on promoting higher-order processing such as explanation, synthesis and application (Yip, 2004) over factual recall. Often questions did not require a specific correct answer and their purpose instead focused on structuring discussions and problem solving or prompting thought processes to assist in conceptualisation. In addition, some lessons had a ‘question theme’, where the aim at the end of the lesson was for students to answer a question which they could not answer at the start. Table 4 provides a detailed description of the specific questions used in each lesson alongside the supporting rationale and the main learning intentions of that episode. The questioning activities in Table 4 have been coded with the help of the literature to the question types outlined in Table 3.

Table 4: Summary of the main questioning and discussion activities adopted in each lesson sequence of the intervention

*[*The final column of this table describes the intended purpose of the activities and refers to question types summarised from the literature in Table 3.]*

Lesson summary and main learning intention(s)	Main Questioning-based Activities	*Question purpose as informed by the literature (See Table 3.)
1 – Introduction to Chemical Reactions		
To explain the difference between a chemical change and a physical change.	Students were asked to discuss their ideas to the main question, with three scaffold questions to support discussion and probe ideas: (Main) What do you understand by the term chemical reaction? (Scaffold) 1- When you hear 'chemical reaction' what do you think of? 2- If you saw a chemical reaction happening – what could you see, or hear, or smell? 3 - Is there anything happening in a chemical reaction that you can't see, hear or smell? Students observed demonstrations of a chemical change (adding potassium iodide to lead nitrate) and a physical change (melting ice) and asked to make notes on the following questions: What can you see happening? Is there anything happening that you can't see? What can you feel happening? (For students holding ice). Student note-taking was followed up by students sharing ideas in pairs and then a class discussion.	(1) Setting stage; (2) Exploring and eliciting student ideas and pre-requisites. As above plus (3) Introduce scientific story; (4) Guiding students to work with scientific concept or idea; refining conceptions and explanations.
2 – Measuring Chemical Change		
To explain atom rearrangement using examples of chemical reactions such as complete combustion.	Students were asked the following questions individually before being asked to share their ideas with their partner and then the class: What is a physical change? What is a chemical change? How are they different to each other? Students were presented with the questions: Why did the cross disappear? What is happening or changing that we cannot see? Students then performed the disappearing cross experiment (addition of sodium thiol-sulphate to hydrochloric acid).	(3) Exploring and eliciting student ideas; (4) Refining conceptions and explanation. (1) Presenting or opening up problem; (4) Guiding students to work with scientific concepts.

3 – Atom Rearrangement		
Describe that in a chemical reaction, bonds are broken and made between atoms.	Paired-student discussion consolidated with class discussion (starter): How could we recognise that a chemical reaction has taken place? Students were provided with questions from lesson 2 and asked to discuss and select a best answer from four possible suggestions. Why did the cross disappear? What is happening or changing that we cannot see? This was consolidated with a class vote and subsequent discussion to allow students to explain their evaluations of each answer. True or false: Students were presented with an incorrect atom diagram of water separating into hydrogen and oxygen molecules and asked to discuss if this showed correct atom rearrangement for water melting.	(2) Exploring student ideas. (4) Refining conceptions and explanations; (4) Guiding towards scientific concept or idea. (5) Guiding students to apply the scientific view in other contexts.
4 – Testing Gases		
Describe three tests that can be used to test for oxygen, carbon dioxide and hydrogen.	What is being produced in this reaction and how do we know? Students watched a video of water being added to effervescence tablets which resulted in the lid being forced off the sealed reaction container. Gas test demonstrations: Dialogue-based questions for example: what is happening? How do we know? In groups of 3 to 4, students were presented with a series of gas test problems which they were asked to discuss. Example: Sally collected some gas in a test tube from a chemical reaction. She wanted to know what gas was present. Sally lit a splint and put it into the tube, the splint carried on burning. Which gas or gases do you know are not present?	(1) Presenting or opening up a problem; setting the stage. (3) Introducing, developing and maintaining scientific story. (4) Getting students to work with scientific concept.
5 – Writing Chemical Equations and Formulae		
Describe the rules we use to write symbol equations for chemical reaction; Explain why we do not lose atoms during a chemical reaction and use	Students discussed a main question and two scaffold questions in pairs or threes: (Main) Do we ever lose atoms in a chemical reaction? (Scaffold) 1 - What is an atom? 2 - What happens to atoms during chemical reactions? Student discussions were consolidated with a class discussion to share ideas. Students were provided with two sheets showing atom diagrams for chemical formula and reactions; balanced symbol equations and word equations. Can we identify some rules to help us write chemical formulae and equations? (Scaffold) 1- What patterns do you spot in the way we write symbol equations? 2-What different kinds of numbers do we use? Can you spot when each type is used?	(2) Exploring and eliciting student ideas and prerequisites; (3) Introduce or develop a scientific story. (1) To present or open up a problem; (4) guiding students to work with scientific concepts

6 – Balancing Chemical Equations		
To apply our rules for balancing equations to new problems.	Students discussed in pairs or threes: What is the difference between CO_2 and 2CO? Students were provided with a worksheet containing five non-balanced equations and asked to work in pairs and threes to discuss how to correctly balance them.	(4) Guiding students to work with scientific concept. (5) Handing over responsibility to students; guiding application of scientific ideas.

Data collection

Data was collected throughout the intervention by both qualitative and quantitative methods. The nature of the data collection methods are summarised in Table 5.

Time Scale and Method	Qualitative or Quantitative
Pre-intervention	
• Initial lesson observations	Qualitative
• MALS questionnaire and survey	Both
• Chemical reactions concept map	Quantitative
Ongoing during intervention	
• Student engagement tracker	Quantitative
• Engagement observations	Qualitative
• Copies of student work	Both
• Voice recordings of student discussions	Qualitative
• Journal style lesson reflection	Qualitative
Post-intervention	
• Student focus group interview (voice recorded)	Qualitative
• MALS questionnaire and survey	Both
• Concept map	Quantitative
• End of unit test score	Qualitative

Table 5: Summary of data collection methods adopted before, during and after the intervention

Questionnaire

Students completed MALS, a 20-item scale validated for use in schools as a reliable tool to analyse students' perception of themselves as learners (Burden, 1998). Students responded to twenty simple statements on a five-point scale depending on their level of agreement. The resulting score is out of 100 and provides a quantitative measure of each student's self-perception. Combinations of scores for particular questions can be totalled to also assess students on ten different factors, highlighted in Table 6.

Students also responded to four open-ended questions (see Appendix 1) which aimed to probe information on students' attitudes towards science and questioning. Responses to the open-ended questions were initially coded using priori categories developed from the literature and predictions of expected answers. Additional emergent categories were developed throughout the coding process to cater for some unexpected responses. Students were asked the same questions alongside the post-intervention MALS questionnaire to assess if their perception of themselves, views or attitudes had changed over the lesson sequence.

Factor 1	Enjoyment in problem solving
Factor 2	Confidence (about school work) Academic self-efficacy
Factor 3	Confidence (about learning ability): Learning self-efficacy
Factor 4	Taking care with work: Careful learning style
Factor 5	(Lack of) Anxiety
Factor 6	Access to and use of vocabulary in problem solving
Factor 7	Confidence in dealing with new work
Factor 8	Confidence in problem solving-ability
Factor 9	Verbal ability/fluency
Factor 10	Confidence in general ability

Table 6: Ten factors of self-perception assessed by the MALS scale (Burden, 1998, pp.299-300)

Concept map

A concept map of chemical reactions was developed from key words identified from the KS3 science specification (see Appendix 2). Students were instructed to link key words with a line and a written description of their relationship. The number of correct linkages was counted and used as a quantitative date source. The concept map was completed at pre-intervention and post-intervention stages and a comparison of scores was between stages to assess student learning.

Assessed work

Throughout the intervention photocopies of student work were taken and marked with a quantitative score as a measure of student learning (Table 7). Examples of student work are shown in Appendices 3-6.

Lesson 1	Book mark of student descriptions of chemical change and physical change.
Lesson 2	Book mark of 'disappearing-cross' practical.
Lesson 3	Marking of atom rearrangement worksheet.
Lesson 4	Exit card requiring students to describe the three gas tests.
Lesson 5	Exit card requiring students to identify difference between 2CO and CO_2 (2 molecules of carbon monoxide and 1 molecule of carbon dioxide) and balance the chemical equation: $Cu + O_2 \rightarrow CuO$.
Lesson 6	Balancing equations worksheet.
Lesson 7	Assessment: End-of-unit test.

Table 7: Summary of assessed work used in data collection

Engagement tracker

At the end of each lesson, students responded to seven statements on a printed engagement tracker (see Appendix 6). The statements probed students on their behavioural, emotional and cognitive engagement. Students were required to respond with a sad, neutral or happy face (corresponding to a score of 1, 2 or 3, respectively) depending on their agreement with each statement. An average engagement score could then be calculated for each student per lesson, with a maximum score of 3 and a minimum score of 1. Averages were also taken as a whole for each individual lesson in the sequence. In addition, statistical analysis was performed to gain correlation coefficients between individual statements to assess if there was any correlation between responses given. As this data was collected directly from the students, the results must be analysed with some scepticism.

Class-teacher engagement observations

Each learning episode was observed by a teacher or a cover supervisor. Prior to the lesson, the observing staff member was briefed on the content and the main questions of the lessons. The observer was also provided with an engagement outline which bullet-pointed factors to identify students exhibiting behavioural, emotional and cognitive engagement (see Appendix 7). The outline was based on information retrieved from the current literature surrounding engagement.

The observations were coded into six priori categories based on positive or negative behavioural, emotional and cognitive engagement. Some comments were coded into an additional category which covered general observation notes regarding general teaching practice.

Audio recordings of lessons

Learning episodes were audio-recorded and relevant parts of class or student discussion were transcribed. The transcripts were then coded under different criteria to identify: the type of questioning used; the type of student and teacher responses; and the style of dialogue used in the classroom.

Post-intervention focus group

The pre-intervention MALS questionnaire scores were used to select a sub-group of students. The scores were arranged from low to high, separately for males and females. A male and female was then selected to represent a low, middle and high score from the class. The sub-group was then asked a series of questions in a focus group style interview (see Appendix 8). A focus group interview was selected due to time constraints of taking students from lessons but also to ask students questions in a relaxed environment with their peers.

Students were asked eight questions which aimed to identify parts of the lessons which engaged or failed to engage them in their learning; their self-perception by asking how they felt when they were asked to discuss in groups or answered questions correctly or incorrectly; and also aimed to identify why students think teachers ask questions. The focus group interview was voice recorded. In addition, to account for quieter students in the focus group, students also made notes on their interview sheets underneath each questions. Both verbal (audio-recordings) and written responses were coded. Initially inductive and non-inductive coding styles were used.

Results and Findings

This section will analyse results from the study and aim to answer the research questions described in the methodology by commenting on the key areas listed below:

1. The impact of pupil discussion centred on key questions to:
    a. Student learning of the Simple Chemical Reactions topic
    b. Student engagement
    c. Students' perception of themselves as learners
2. The use of questioning as a method of scaffolding learning

The impact of pupil discussion centred on key questions to student learning of the Simple Chemical Reactions topic

The average score (number of correct links) on the pre-intervention concept map was 0.80 per student. Ten students were unable to make any correct links, scoring zero, and on average students each made two incorrect links. The average score on the post-intervention concept map was 5.5 per student and on average students made 0.4 incorrect links. All students increased the number of linkages they could provide between the pre and post-intervention by an average of 4.7 links, ranging from 1 to 10.

The average end-of-unit test score for the 'Simple Chemical Reactions' topic was 43.6%. As a comparison average scores were taken for the four chemistry topics assessed prior to this topic (46.3%), as well as the latest science assessment, P4 – Energy Sources (40.0%). This data is summarised in Figure 1. On average students scored 2.7% less on the Simple Chemical Reactions topic compared to the other chemistry topics in the scheme of work.

It is problematic to compare data between scores of different assessments, due to potential imbalances in the topic or assessment difficulty. This is perhaps shown by the higher average mark for 7N for topic C2, at 58.3% compared to P4, at 40.0% (Figure 1) Therefore, as a comparison, test data for the Year 7 group as a whole has been displayed alongside data for Year 7 in Figure 1.

Data from pre and post-intervention concept map scores and end-of-unit test scores were compared (Figure 2). There was found to be a moderate positive correlation between post-intervention concept map score and students' end-of-unit test score for Simple Chemical Reactions. There was no relationship observed between the initial concept map score and the end-of-unit test score.

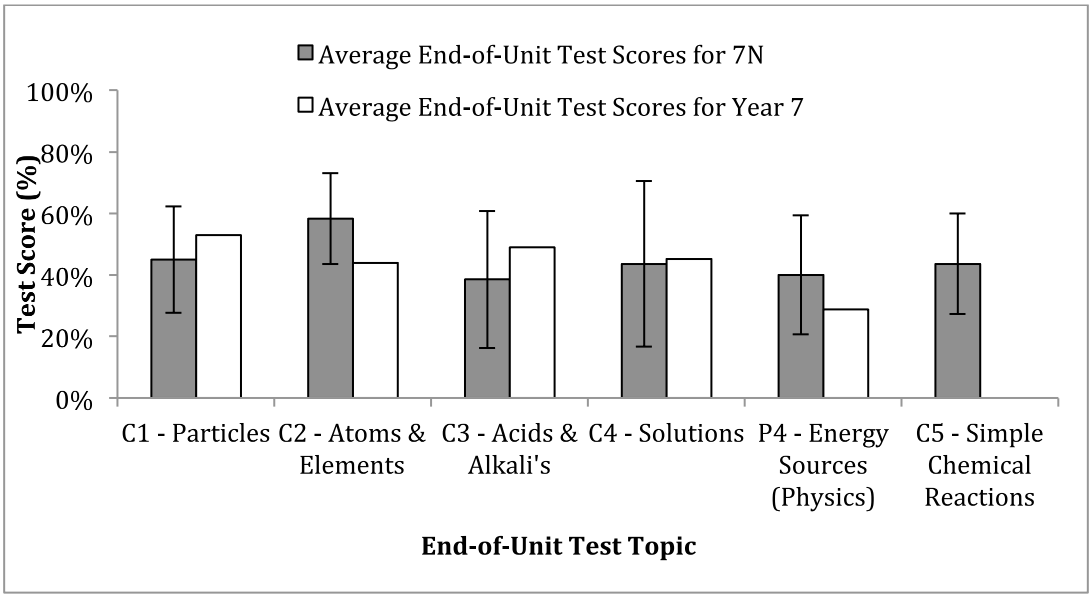


***Figure 1: Chart showing end-of-unit test scores for class 7N and the entire Year 7 age group**

*Displayed percentage scores are for the 4 chemistry topics assessed prior to the intervention (C1-C4), the latest end-of-unit science test (P4) and the scores for the Simple Chemical Reactions (C5) assessment. Error bars show ±1 standard deviation. At the time of writing no test score data was available for the remainder of the year group studying C5.

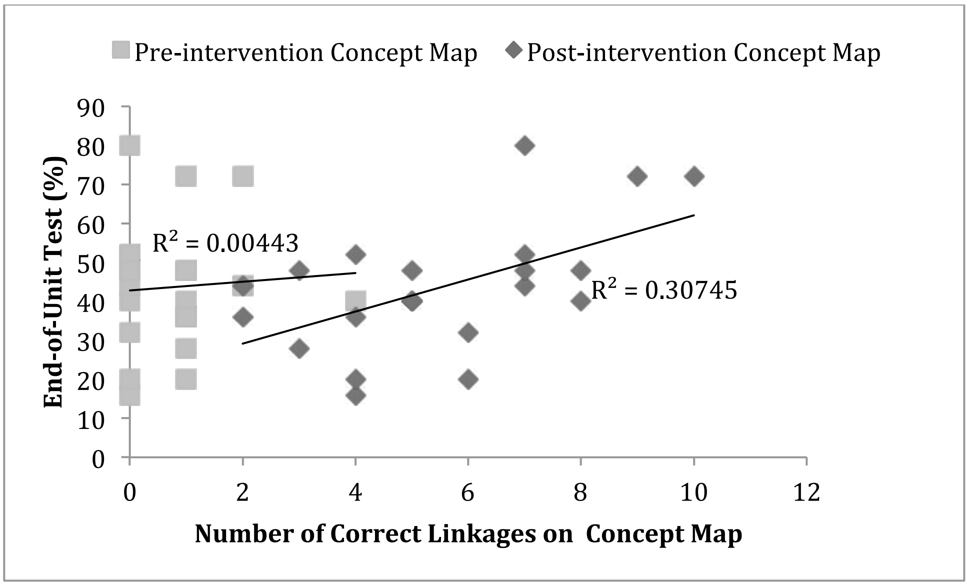


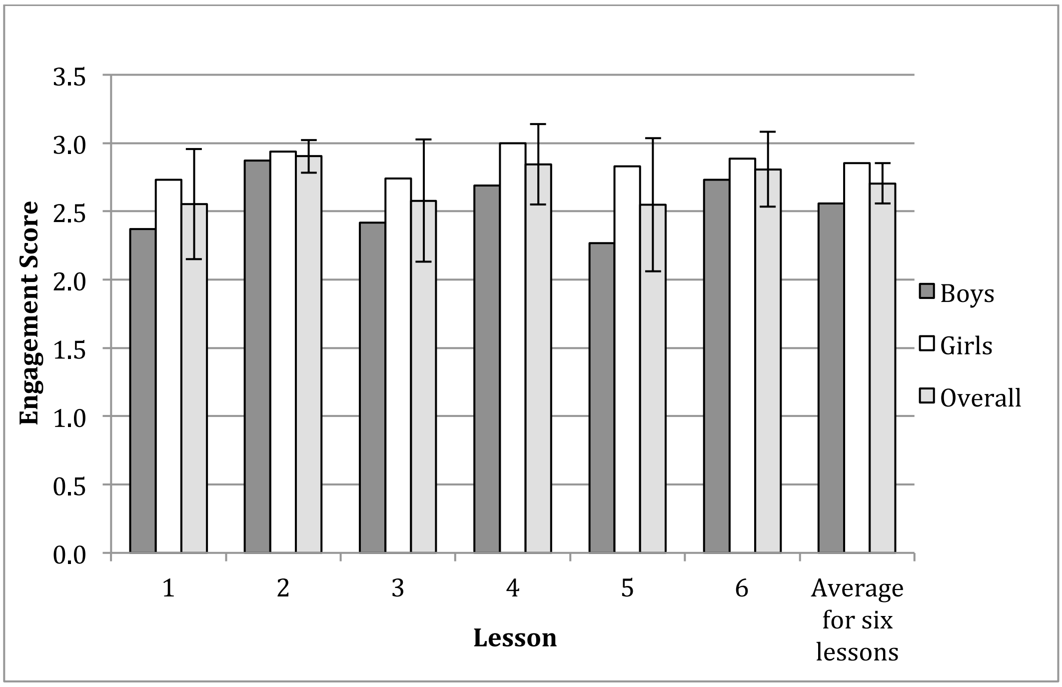
Figure 2: Plots showing comparison between pre and post-intervention concept map scores and subsequent end-of-unit test scores for Simple Chemical Reactions (%)

The impact of pupil discussion focussed on key questions on student engagement

Engagement tracker results

Analysis of engagement tracker results showed that students exhibited high levels of overall engagement across the lesson sequence. The average engagement score over the six lessons was 2.75 out of a possible 3 (2.6 for boys, 2.9 for girls). Average engagement scores for individual lessons varied from 2.3 to 2.9 (lesson 5 and 2, respectively), for boys and from 2.7 (lessons 1 and 3) to 3.0 (lesson 4), for girls. These results are summarised in Figure 3.

This study did not set out with intentions to investigate the difference between engagement of boys and girls. However, results shown in Figure 3 demonstrate that on average girls' engagement was higher than boys' for each lesson. In addition girls' results showed much less variation; the average standard deviation for student engagement scores for each lesson was 0.1 for girls and 0.4 for boys. This could reflect on girls being more engaged in the lessons. However, the engagement tracker results were produced from data collected from students and therefore, could reflect on how girls and boys respond differently to questionnaires about their behaviour.



[*]**Figure 3: Chart showing the average engagement score for each lesson**

[*]Results are shown separately for boys and girls as a comparison. Error bars show ± 1 standard deviation.

Across the lesson sequence the overall lowest average score was in response to statement 3: ‘I was interested in this lesson’ (2.5 for boys, 2.7 for girls). Correlation coefficients were calculated to observe relationships between scores for the individual statements and a summary of these are shown in Table 8. No significant correlation was found between students’ responses to statement 1 (my behaviour was right for learning) and statement 3 or between statement 4 (I was focused on learning) and statement 3. This suggests that even if students did not find the task or lesson interesting (emotional engagement) they are still able to exhibit positive behavioural and cognitive engagement.

	Girl	Boys	#	1	2	3	4	5	6	7
My behaviour was right for learning	3.0	2.7	1	1.0						
I was on-task this lesson	2.9	2.6	2	0.8	1.0					
I was interested in this lesson	2.7	2.5	3	0.4	0.6	1.0				
I was focused on learning	2.9	2.6	4	0.8	0.9	0.5	1.0			
I put in a lot of effort	2.8	2.5	5	0.6	0.9	0.6	0.7	1.0		
I was willing to try the activities even if they were hard	2.8	2.6	6	0.6	0.6	0.6	0.7	0.5	1.0	
I put a lot of thought into the work I was doing	2.9	2.6	7	0.8	0.8	0.5	0.8	0.8	0.7	1.0

[*]Table 8: Average student response scores for individual statements on the engagement tracker

[*]Scores displayed separately for girls and boys (columns 2 and 3, respectively).
Calculated correlation coefficients for statements 1-7 from the student engagement tracker are also shown.

As practical work is known to be engaging to students in science (Wellington & Osborne, 2001), a comparison was made between those classes that had a practical element included and those that did not. Importantly, those lessons that did contain a practical element still had the same focus on discussion-based questioning as those that did not contain a practical element (see Table 4). There was a 0.2 point difference in overall student engagement between the lessons that contained a practical element (lessons 1, 2 and 4) compared to those that did not (lessons 3, 5 and 6). Analysis of individual statements (Table 9) showed students on average were more interested in those lessons that had a practical element (statement 3) however they identified that they put more thought into and equal amounts of willingness and effort into lessons without practicals. This suggests students were more interested (emotional engagement) in those lessons that contained a practical. However, as there is little difference (0.2) in the average overall engagement scores, this suggests that less interest did not influence students’ behavioural and cognitive engagement.

Engagement tracker statement		Lessons with practical element	Lessons without practical element
1	My behaviour was right for learning	2.9	2.8
2	I was on-task this lesson	2.8	2.7
3	I was interested in this lesson	2.7	2.4
4	I was focused on learning	2.8	2.6
5	I put in a lot of effort	2.7	2.7
6	I was willing to try the activities even if they were hard	2.7	2.7
7	I put a lot of thought into the work I was doing	2.7	2.8
Average		2.8	2.6

Table 9: Comparison of results for student engagement tracker for lessons with and without a practical element

Lesson observation results

The difference in engagement between genders was also highlighted by the lesson observations. All instances of negative behavioural engagement were identified as being displayed by boys (Table 10).

Lesson 1:	'Named boy distracting some students'
Lesson 2:	'Only a couple of boys had a little chat'
Lesson 3:	'Named boy trying to be defiant, not following simple instructions'
Lesson 4:	'80% of students on task, few boys needed speaking to'
Lesson 6:	'Named boy slow in settling down'

Table 10: Quotations taken from lesson observations to highlight instances of poor male engagement

Lesson observation analysis also identified the high emotional engagement during practical activities. Students were identified as showing excitement, enthusiasm and reacting positively towards practicals. During lesson 1, students observed and made notes on a demonstration of a physical change and a chemical change. Students' observations were directed by the scaffold questions (see Table 4). During the subsequent discussion of the key questions students were identified as displaying further emotional and cognitive engagement. However, some students were described as losing interest during the transition to the discussion and subsequently became unengaged (see Table 11).

During lesson 4, students observed demonstrations of two gas tests (for oxygen and hydrogen) and also performed their own test for carbon dioxide. All students were identified as being behaviourally, emotionally and cognitively engaged. In contrast to the first lesson, all students were also were identified as more willing to discuss their ideas. Students were identified as asking 'thoughtful and intriguing questions', demonstrating deeper cognitive engagement in the activities. This could suggest that by the fourth lesson in the sequence students were more willing to engage in discussion-based activities than at the start.

Lesson 1:	Students enthusiastic to help with a demo and excited when describing results of reaction; Students willing to share their work with the whole class! Giving their ideas about what might happen when the substances are mixed; some lost interest when discussing what they saw at the demonstration.
Lesson 2:	*Anonymised named boy* asked questions that showed deeper interest into the topic/practical. (cognitive engagement).
Lesson 4:	Students amazed by gas tests. Teacher questions during practical kept students interested. Students were happy to discuss the test and quiz in pairs and were asking thoughtful and intriguing questions.
Lesson 5:	'All students showed positive conduct and participated in the learning activities; most students were happy to contribute; students were very willing and interested in trying to work out how chemical equations were set out; all students were focused on their learning and focusing hard on mastering the science behind working out a chemical equation'
Lesson 6:	'Reacted positively to activities; students showed resilience towards a difficult task. Nearly all students were starting to use a metacognitive approach to work out how equations balanced'

***Table 11: Quotations taken from lesson observations to highlight instances of behavioural, emotional and cognitive engagement**

*Key engagement indicator words as identified by the literature are underlined.

Analysis of lesson observation notes showed that high levels of positive cognitive engagement was also evident in the lessons that did not contain practicals, particularly in lessons 5 and 6. During these lessons, students were carrying out a discussion-based problem solving tasks in small groups (2-3 students). By this stage in the sequence students were identified as displaying strong cognitive and emotional engagement. This is particularly evident in lesson 6, were students openly expressed how difficult the task was but also demonstrated their determination and interest in solving the issues at hand.

One area identified from both audio recordings and mentor observations is that during small group discussions, students still sought out teacher approval rather than discuss their findings with their peers; (*Lesson 5:* Students had a light bulb moment they could not wait to show *teacher* they understood).

Audio recordings

Audio recordings of lessons and student discussions revealed instances of student engagement in each lesson sequence. Transcripts of the recordings were coded for the three different types of engagement as informed by the literature. Example quotes of each engagement type, along with their context, are presented in Table 12.

Context	**Quote**	**Engagement type**
Lesson 2: Group discussion on: why the X underneath the beaker 'disappeared' during the practical. Due to time constraints the discussion was cut short and students were told we would look at the answer next lesson.	'But what is going on that we can't see? I want to know! I don't want to wait until next week to find out.'	Emotional and cognitive engagement.
Lesson 4: A student response at the end of lesson containing observations of gas tests.	'Miss that lesson was brilliant'	Emotional engagement.
Lesson 5: Three students discussing 'Do we ever lose atoms in a chemical reaction?'	*Student 1*: I don't think we can destroy or create atoms though. Can we? *Student 2:* Yes I agree. *Student 3:* You can't. It's just everything's rearranging. *Student 2:* I don't think they disappear, they'll just like spread. *Student 1:* Like in that reaction when we made the pop. That was because of the hydrogen. But it didn't keep popping. I don't think that was because we lost anything, I think it just spread out around the room. *Student 3:* But I think it's probably still there, just spread out. I think anyway. *Student 2*: Like when you make gas it spreads out!	All students engaged in discussion. Behavioural, emotional and cognitive engagement.

Table 12: Students exhibiting behavioural, emotional and cognitive engagement

Questionnaire

Responses to question four (do new ideas in science excite or interest you?) from the pre and post-intervention survey questions were analysed and coded for three types of response: positive, neutral and negative (see Figure 4). Pre-intervention results showed that 6 out of 21 students responded negatively to being interested in new ideas in science; 6 students responded positively; and 9 out of

21 students responded neutrally. Neutral responses usually included comments such as ‘just a little, sometimes or depends’; one student commented ‘New idea don’t excite me, but make me curious’.

Post-intervention questionnaire results show that 12 out of 21 students responded positively, 7 responded neutrally and 2 responded negatively. This represents an increase from 29% of students being interested or excited by new ideas at start of the intervention to 57% at the end of the intervention. In addition, 29% of students responded negatively to being interested or excited by new scientific ideas, compared to only 10% at the end of the intervention.

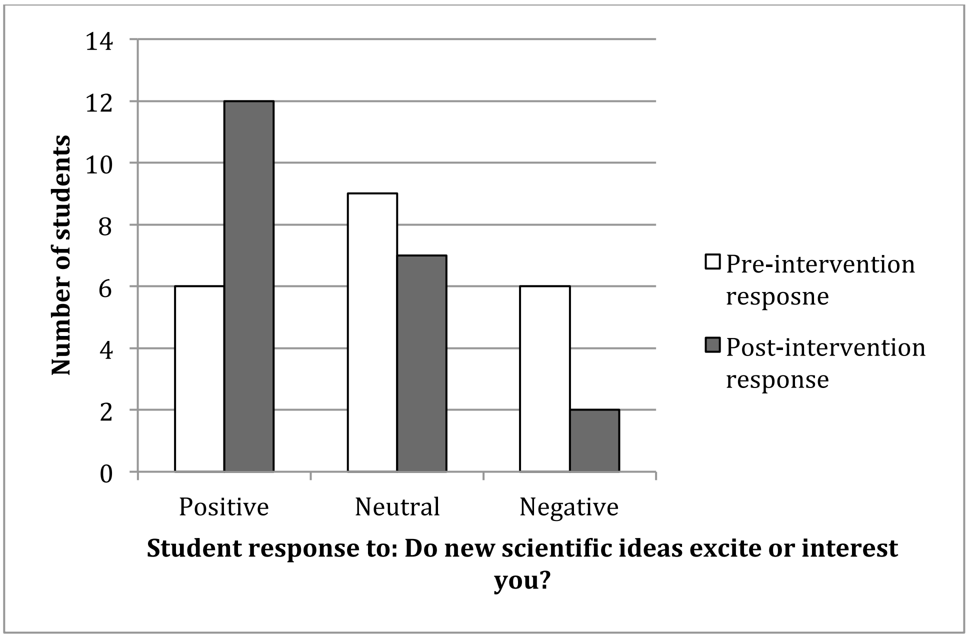


Figure 4: Chart displaying students' responses to 'Do new scientific ideas excite or interest you?'

Focus group interviews

During the post-intervention focus group students were asked three questions relating to their engagement in lessons (Table 13).

Question 1	What have you enjoyed the most about these lessons on chemical reactions?
Question 2	Think about a time when you were really interested, putting in a lot of effort and trying hard in one on my lessons. What made you do that?
Question 3	Think about any lesson when you weren’t interested at all and did not try very hard, you might even have been misbehaving. What made you do that?

Table 13: Interview questions asked to six students in the post-intervention focus group

All six of the focus group students said practicals were one of the things they enjoyed the most about the lessons. Students also described practical activities as one of the reasons that they are likely to be interested, put in effort and try hard in a lesson. Two of the six students in the focus group said they also enjoyed discussing with their partners; and again regarded this as a reason that would maintain interest, put in effort and try hard. One student commented in reference to the problem solving task to find out the rules for writing chemical equations: "*Lessons are much more fun when I get to work with (points at partner), like when we were figuring out the difference between the big or small numbers, that made me want to work hard at it.*"

Student responses to being unengaged fitted into four categories: classroom environment; not having enough knowledge; and boredom or lack of interest in activities. The latter being the most popular response. A response to question 3 is transcribed below.

> ***Student***: I was bored like when we started the six lessons.
> ***Teacher:*** You were bored at the start?
> ***Student:*** Yes
> ***Teacher:*** If you were bored at the start, does that something changed by the end? Have a think about why.
> ***Student****:* (Pauses) I know why I wasn't bored at the end. Like at the beginning I thought you were going to make us write down like every single thing.
> ***Student 2****:* That's quite boring.
> ***Student:*** Yeah I'd rather talk about something than write it down.

The impact of pupil discussion on students' perceptions of themselves as learners

The average MALS score at the pre-intervention stage was 63.55 (63.5 for girls, 63.6 for boys) with a standard deviation of 13 (9 for girls, 16 for boys) (Figure 5). At the post-intervention stage, the average score was 66.5 (67 for girls, 69.3 for boys) with a standard deviation of 11 (7 for girls, 14 for boys) (Figure 6).

Twelve out of twenty-one students showed a positive increase in their MALS scores between the pre and post-intervention stages; one student stayed the same and eight students showed a decrease in their score. On average scores increased by 2.8 points between the pre-intervention and post-intervention stages. The largest increase in score was observed from three boys with the lowest MALS score; at the pre-intervention stage the three lowest boys' scores were 38, 44 and 49, compared to 69, 65 and 87, respectively at the post-intervention stage. This represents an average increase of 25 points.

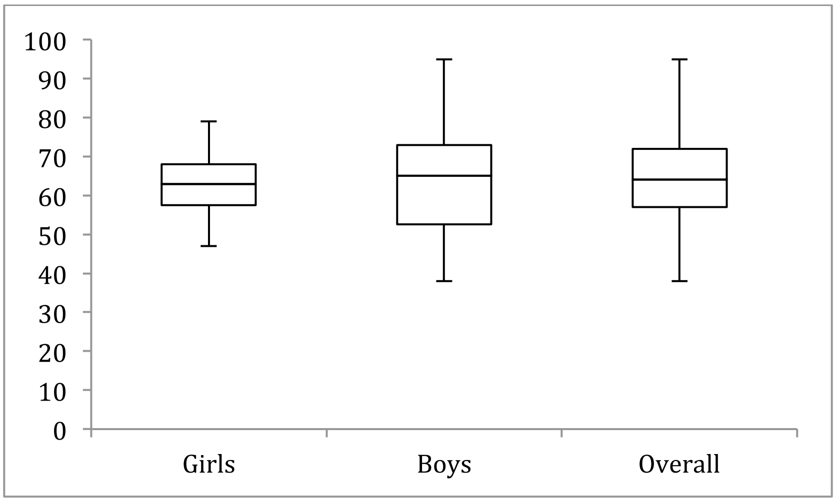


*Figure 5: Box and Whisker Plot showing pre-intervention MALS scores**

* Results are presented individually for boys and girls as well as combined. Plots show the median, upper and lower quartiles as well as the minimum and maximum scores.

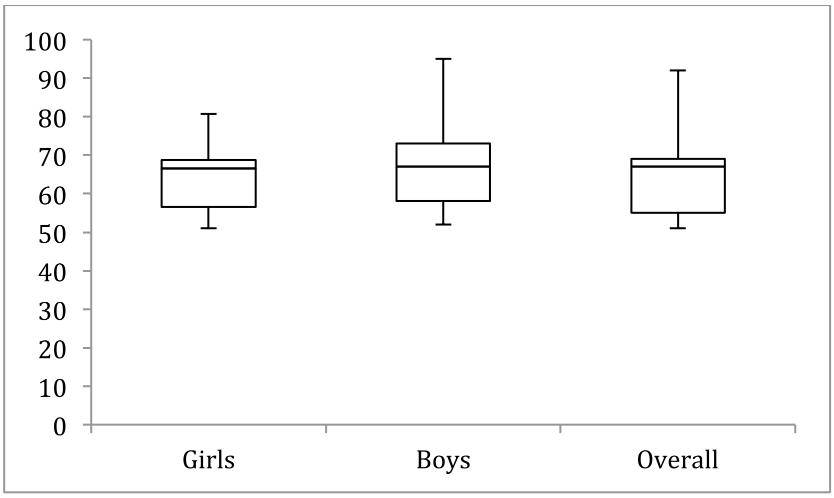


*Figure 6: Box and Whisker Plot for post-intervention MALS scores**

* Results are presented individually for boys and girls as well as combined. Plots show the median, upper and lower quartiles as well as the minimum and maximum scores.

Percentages scores for individual factors assessed by MALS are shown in Table 14. Scores are presented as percentages for the purpose of comparison between pre and post-intervention averages. The factors with the biggest increase in score were confidence in general ability (+9.6%), verbal ability and fluency (+8.2%) and access to use of vocabulary in problem solving (+7.3%).

Factor		Pre-intervention average	Post-intervention average
1	Enjoyment in problem solving	64.7%	64.6%
2	Confidence (about school work) Academic self-efficacy	65.8%	65.5%
3	Confidence (about learning ability): Learning self-efficacy	62.3%	62.1%
4	Taking care with work: Careful learning style	72.9%	76.7%
5	(Lack of) Anxiety	63.1%	68.1%
6	Access to and use of vocabulary in problem solving	56.5%	63.8%
7	Confidence in dealing with new work	62.1%	68.1%
8	Confidence in problem solving-ability	65.1%	63.8%
9	Verbal ability/fluency	56.6%	64.8%
10	Confidence in general ability	66.6%	76.2%

Table 14: Breakdown of the individual factors assessed by MALS

Students' attitudes towards questioning

Before the intervention, 62% of students in 7N expressed that they thought teachers ask questions to manage behaviour or to test them. 33% of students believed that teachers asked questions to benefit their learning. In contrast, after the intervention, 11% of students believed teachers asked questions to test them and 16% as behaviour management. In addition, 68% of students responded to say teachers ask questions to benefit their learning. This data is summarised in Table 15. In addition 100% of students in the post-intervention focus group expressed that they felt embarrassed when they got an answer to a question wrong.

Response category	Pre	Post	Example comments
Test	33%	11%	To see if I know it; to test me
Behaviour	29%	16%	To see if you are listening; mostly to make sure I am paying attention; catch me out when I'm not listening
Task management	5%	5%	To check we know what to do
Benefit learning	33%	68%	To see what we already know; so the teacher knows we are at the same point, and if not support those who are behind; to try to help you

Table 15: Responses to the question 'why do you think teachers ask questions?' coded into four emergent categories

The use of questioning as a method to scaffold learning

To analyse the use of discussion and questioning as a method of scaffolding learning, some extracts of dialogue from two separate learning episodes are analysed below.

Lesson 1

The learning intention of lesson 1 was for students to be able to *describe the difference between a chemical and a physical change.* Students made observation notes on a demonstration of a chemical and physical change. Two scaffold questions were used to structure students' thoughts and subsequent notes during the demonstration (see Table 4). Students then used their notes to participate in a paired discussion and then a class discussion. Analysis of exit cards showed that 61% (11 students out of 18) demonstrated understanding of the difference between chemical and physical change; 28% (5 students) demonstrated an incorrect understanding of chemical and physical change and 11% (2 students) left the answers blank. Extracts of transcribed audio recordings of the class discussion are shown below:

Discussing physical change:

Student 1**:** The ice was melting, we could see that. And it felt cold and wet too in my hands.

Teacher: What was going on that you couldn't see?

Student 1: I think maybe it changed from a solid to a liquid (pauses), but then we could see that.

Teacher: What about another group – what do you think?

Student 2: It's the change in state and something is happening with the particles.

Discussing chemical change:

Student 1*:* When the two chemicals from the bottles were mixed they turned yellow.

Teacher: So that was what we could see. We mixed lead nitrate and potassium iodide and it turned yellow. What about what was going on that we could not see?

Student 2*:* Something with the particles.

Teacher: So we said when the ice melted something was happening with the particles. Do we think this is the same kind of thing?

Student 3*:* Because something happened to change the particles in the ice, in our hands the cubes they turned to water, but then if we collected that and put it into the freezer we could get it back to ice. I'm not sure how we could get the yellow stuff back to what it was.

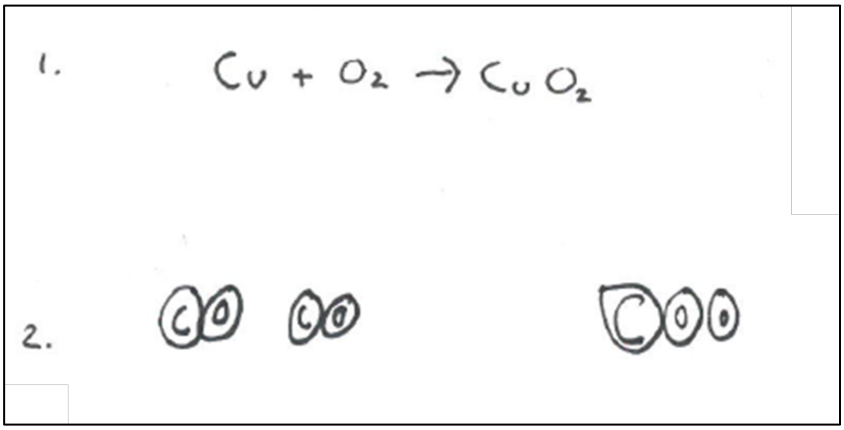
Lesson 5

The learning intention of lesson 5 was: *to describe the rules we use to write and balance chemical symbol equations.* The 18 students present were divided into six groups of three and provided with examples of atom diagrams for chemical formula and the corresponding balanced symbol equations and word equations. Students were also provided with a set of questions to scaffold the discussion (see Table 4). Transcribed extracts of the students discussing the key questions are shown below.

> ***Student 1*:** So for the $2H_2O$ (Spells out 2-H-2-O), there's a big two because there is two of them. And then there is a little two because in each one of those there are two hydrogens.
> ***Student 2*:** The small number represents how many of the chemical in a molecule and the big numbers represent how many molecules.
> ***Teacher*:** Good. We've used a big two because we have two molecules of water. And the small two is used after the H to show there are two hydrogens in each water molecule.

All six groups correctly identified when a subscript number should be used, when a large number should be used and that the same symbol (e.g. C, O or N) was always used for the same chemical. One group identified that reactants should be on the left of the arrow and products on the right. Two groups also identified the correct use of arrows and plus symbols. Exit card results showed that 83% of students (15 students out of 18) correctly identified the difference between CO_2 (1 molecule of carbon dioxide) and 2CO (2 molecules of carbon monoxide). 17% of students (3 students) failed to respond to the question. All students responded incorrectly or failed to respond to the balancing equation question ($Cu + O_2 \rightarrow CuO$). The most popular response amongst the incorrect students was to add a subscript number 2 next to the 'O' on the reactants side (see Figure 7). This response was used to inform the next lessons teaching as I realised I had not told students that only large numbers could be changed and not the subscript numbers when balancing equations.

Within the end-of-unit test there were two questions that required application of the scientific ideas addressed in lesson 5. Question two required students to identify the number and type of each atom from a formula and to write chemical formulae from written descriptions. Question three asked students to write and balance a symbol equation for the complete combustion of methane. The average score for question two was 5.5 out of a possible 8 (68.8%), with a modal score of 6. In contrast the average score for question three was 0.55 out a possible 3 (6.9%). The highest mark achieved was 1, which required students to write the chemical equation without balancing it.



[*]Figure 7: A student's exit card from Lesson 5 demonstrating incorrect usage of subscript numbers

[*]Students were asked to balance a chemical equation ($Cu + O_2 \rightarrow CuO$) and draw atom diagrams to show the difference between 2 molecules of carbon monoxide (2CO) and 1 molecule of carbon dioxide (CO_2). Credit was given for incorrectly drawn atom diagrams, as this had not yet been covered with Year 7.

Summary of results

- Teaching and learning with a focus on discussion and questioning could improve students' perceptions of themselves as learners; particularly their confidence in general ability, verbal ability and fluency and access to use of vocabulary in problem solving. This impact could be more profound in male students who already have a low perception of themselves as learners.
- Students perceive questions as teachers' methods of testing them and there is a degree of embarrassment and anxiety surrounding answering questions wrong.
- Lessons with a focus on discussion and questioning do promote positive engagement, more so in girls than boys.
- It is inconclusive whether the intervention described improved overall learning of chemical reactions due to incomparability of test scores of different units.
- Questioning and discussion-based activities can be used to scaffold learning of some parts of learning chemical reactions. However, both formative and summative assessments showed that there were gaps in student application of knowledge.

Discussion

In agreement with Mortimer and Scott (2003), this study has shown that discussion focussed on key questions can be used to scaffold learning and promote the conceptualisation of scientific ideas. Mortimer and Scott (2003) provide a framework of six discussion purposes (Table 1) that are highlighted as being in line with Vygotsky's sociocultural approach to learning. They provide a path of the conceptualisation route from a student initially being presented with a new idea in a social context to that idea becoming internalised within the student.

When planning the intervention, these teaching purposes supported by questioning styles outlined by Kawalkar and Vijapurkar (2013) were applied to give the questioning and discussion activities a rationale in how they would support student conceptualisation and subsequently scaffold learning (Table 3). The aim of the scaffold questions in lesson 1 were to open up the idea to students that in both the chemical and physical change there is something happening that could not be seen. The subsequent discussion aimed to explore student views: by using an interactive-dialogue approach to explore students' everyday ideas about chemical and physical changes. Open questions explored student views and at this point no answers were evaluated or listed as wrong. The consolidation of the discussion aimed to introduce and develop the scientific story: by shifting to a more dialogic-non-interactive approach to communication by identifying and focussing on student responses to define between a chemical and physical change. 61% of students were then able to provide a correct description of chemical and physical change at the end of the lesson.

The aim of the question-based discussion activity in lesson 5 was to present and open up the problem of writing chemical equations. Students were provided with scaffold questions to assist them in identifying the rules for writing chemical formulae and equations. Students performed well on the end-of-unit test question which required them to both write and interpret chemical formula. They demonstrated their ability to apply and work with the ideas they had conceptualised in the lesson to new and abstract problems. However, students performed poorly on the question which required them to balance the equation. Approximately half the class demonstrated that they could write out the chemical equation for methane burning in oxygen; however, no students managed to successfully balance the equation.

The final stage of teaching and learning described by Mortimer and Scott, *handing over responsibility to the student* highlights the teacher's role as offering opportunities for students to rehearse and work with the ideas they have been learning. It is here where I acknowledge the intervention fell down. For example, using questioning to structure students' thoughts about a physical change and a chemical change worked well here for the purpose of introducing and developing the scientific story. Analysis of the dialogue from audio recordings during the demonstration and the subsequent discussion revealed students were discussing the idea that something different was happening with the particles in a chemical and physical change. However, results from the exit cards of that lesson showed approximately 40% of students failed to write down the difference between chemical and physical change. This suggests that complete internalisation of the idea had not been made. At this point, perhaps students would have benefited from additional opportunities to work with the ideas that they had been introduced to support their full internalisation. Questioning and discussion worked well to introduce and develop the idea of chemical and physical change, amongst others, but an additional step was needed in the learning journey to fully support internalisation and meaning making. To assess whether this additional opportunity could be provided through discussion, additional investigation in a second phase of action research will need to be performed.

Aside from questioning, Wellington and Osborne (2001) provide a selection of activities that can be used to promote discussion in the classroom. These include thing such as incorrect concept maps, concept cartoons, a discussion of misconceptions and directed activities related to text (DARTs). Wellington and Osborne (2001) support that these kinds of activities promote meaningful discussion requiring higher-order skills such as which in turn supports conceptualisation and use of the scientific language.

Although the importance of discussion to learning and conceptualisation of new ideas is demonstrated widely across educational research, the literature highlights the importance of students needing assistance with discussion (Kawalkar & Vijapurkar, 2013). Few students can freely proceed with a fruitful and meaningful discussion that supports the internalisation and conceptualisation of new ideas. Hewitt (2014), expresses that for talk to be meaningful towards learning it must be properly planned and structured by the teacher. Students work best when they can see a sense of purpose towards the task they are doing (Wellington & Osborne, 2001). Scaffolding discussion with clear success criteria is suggested as a method to improve student discussion; students need to know precisely what they need to talk about to be successful.

Therefore, I argue that questioning can be used as a method to scaffold meaningful scientific discussion between students.

An area that questioning and discussion did appear to support was practical work. Practical work is described as being supportive towards learning when it is effective both in the domain of objects and observables and in the domain of ideas (Millar & Abrahams, 2009). A common pit-fall of practical work is that the link between these two domains in insufficient (Wellington & Osborne, 2001). Often students successfully follow a practical procedure and observe what they were intended to observe, but fail to make the link to the scientific ideas addressed (Millar & Abrahams, 2009).

For the practical activities in lessons 1 and 2 to be successful in the domain of objects and observables students would have observed the physical and chemical changes. However, to be effective in the domain of ideas, students must have also engaged thoughtfully to link their 'doing' with the scientific ideas that were intended (minds-on) (Millar & Abrahams, 2009). Lewthwaite (2014) acknowledges that practicals are used in chemistry often as a formality of tradition and convenience. Chemistry is typically portrayed as a practical subject and teachers thoughtlessly assign practicals to their lessons believing students must engage in these hands-on activities before they will believe and learn chemical phenomena. Evidence from observations and audio recordings (see Tables 13 and 14, respectively) show that students were engaged in meaningful dialogic discussion about the ideas developed in the practical activities. I therefore, argue that the discussion-based questions used to scaffold such practical activities in this intervention made the link between the domain of objects and observables and the domain of ideas more explicit and subsequently supported the conceptualisation of scientific ideas (Needham, 2014).

This action research intervention also investigated the wider impact of using discussion and questioning in the classroom. It is recognised that student engagement and academic self-perception can dip on the transfer to secondary education (Fredricks, Blumenfeld, & Paris, 2004; Norgate, Osborne, & Warhurst, 2013). Evidence from this intervention suggests that certain pedagogies such as questioning and discussion can engage students and improve their academic self-perception in the short-term. However, engagement and self-perception are both described as multifaceted. Definitions of these terms in the context of schooling and education address much more than a student's attitude in just one lesson. For example, educational engagement refers to a student's appreciation of and engagement in wider-school life. Students were engaged in studying chemical reactions, however their attitudes towards and engagement in other aspects of schooling were not investigated by this study.

Future recommendations and research

The trending shift away from 'classic science teaching' characterised by lecture style monologues and knowledge transmission provides an opportunity for teachers to experiment with new teaching strategies. The observed increase in students' confidence in general ability, verbal ability and fluency and access to use of vocabulary in problem solving is worth investigating further; particularly the large increase seen from the male students who began the intervention with the lowest MALS score.

At the onset of this study, many students found discussion difficult. By the end of the intervention, this had showed improvement; students were more accustomed to being asked to discuss something and needed less encouragement to get going. This could be linked to the improvement in their academic self-perception. However, audio recordings and observational data showed that many students wanted to seek approval of their answers from myself rather than share it in their peer-group. In addition, observation from audio recordings and engagement data showed that it was generally the higher attaining students that were more likely to take an active role in discussion around questions. Therefore, I support that both peer and classroom discussions are important learning activities that students need to be taught how to do it and importantly practice.

In the next cycle of action research, I would propose an intervention that still focuses on using discussion around key-questions as a method of scaffolding learning. However, I would also incorporate other activities into the lessons to support all six parts of the teaching and learning process proposed by Mortimer and Scott (2003), particularly the handing over of responsibility of the scientific knowledge. Discussion is an important part of the conceptualisation of new ideas; however, I think it is reasonable to suggest that in this intervention there were instances where students were given a discussion task when a different approach to learning could have been more effective. I therefore support that questioning can be used to scaffold learning as part of wider repertoire of classroom activities. For example, students should also be provided with the opportunity to rehearse and practice the ideas they have learned which does not necessarily have to be on a social plane of discussion and could include a student working individually on problems. A second cycle of this action research would therefore focus on how quality discussion-based questioning activities can be used to scaffold learning over quantity.

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Appendix 1

Pre and post-intervention questionnaire:

asked in addition to 'How I See Myself' MALS (Burden, 1998)

Name:

Date of Birth:

1) How do you learn best in Science?

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………

2) Who helps you to learn best in Science?

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………

3) In your Science lessons, why do you think teachers ask you questions?

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………

4) Do new ideas in Science excite or interest you?

……………………………………………………………………………………………………

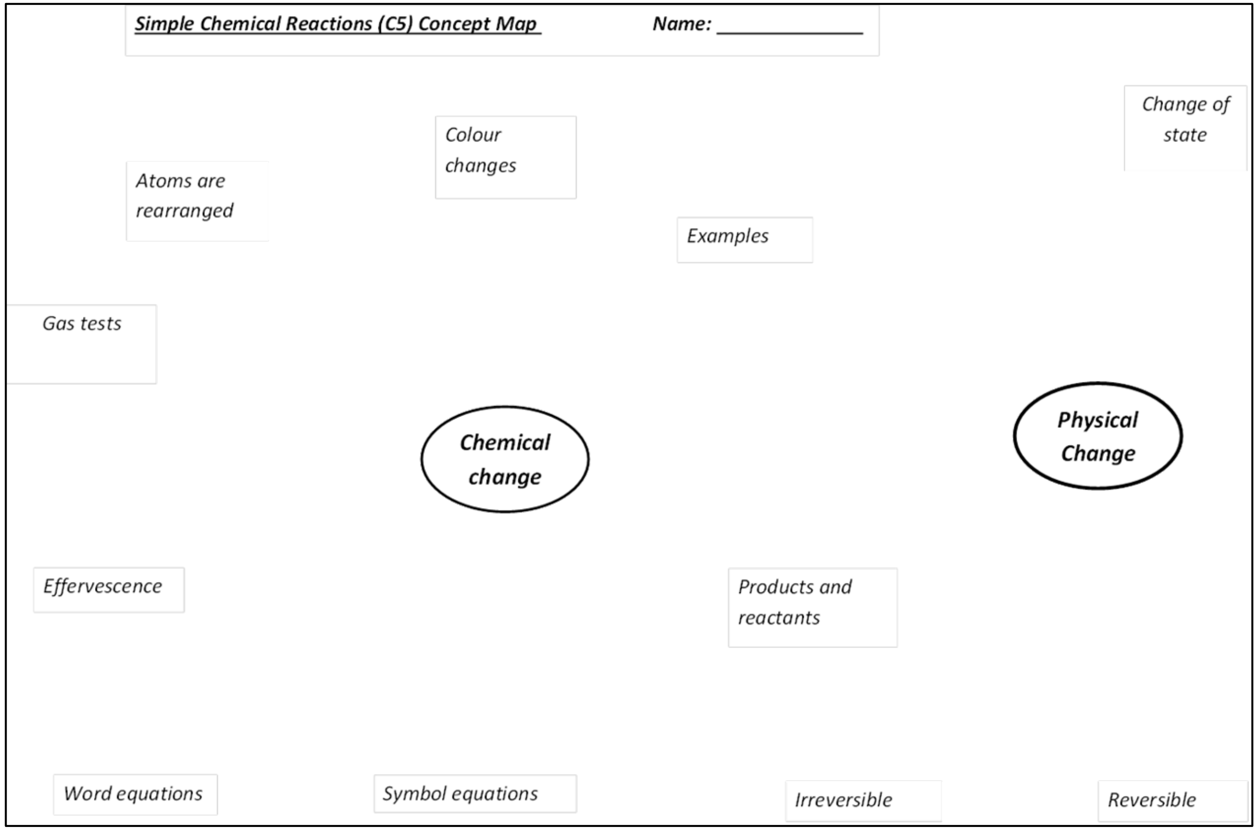
……………………………………………………………………………………………………

……………………

Appendix 2

Simple Chemical Reactions concept map

Students completed the concept map at pre and post-intervention stages



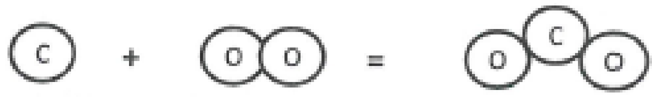
Appendix 3

Rearranging atoms worksheet used as an assessment of learning during lesson 3

Rearranging Atoms

When a chemical reaction takes place, the atoms in the reactants become arranged differently to produce the products.

Chemical bonds are broken between atoms in the reactants. New chemical bonds are made between atoms in the products.



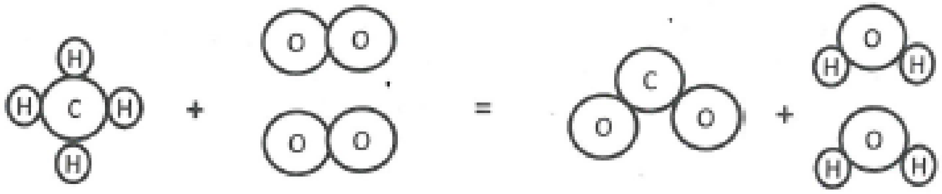
Carbon + Oxygen = Carbon dioxide

1) What bonds have been broken? the oxygen bonds have been broken ✓

2) What new bonds have been made? carbon bonds have been made ✓

Burning Fuels

Atoms are rearranged when we burn fuels in oxygen. This means a chemical reaction has occurred. Methane is a fuel that we can burn.



Methane + = Oxygen ✓ = carbon dioxide + water ✓

3) What bonds have been broken? Oxygen bonds and methane ✓

4) What bonds have been made? carbon dioxide and water ✓

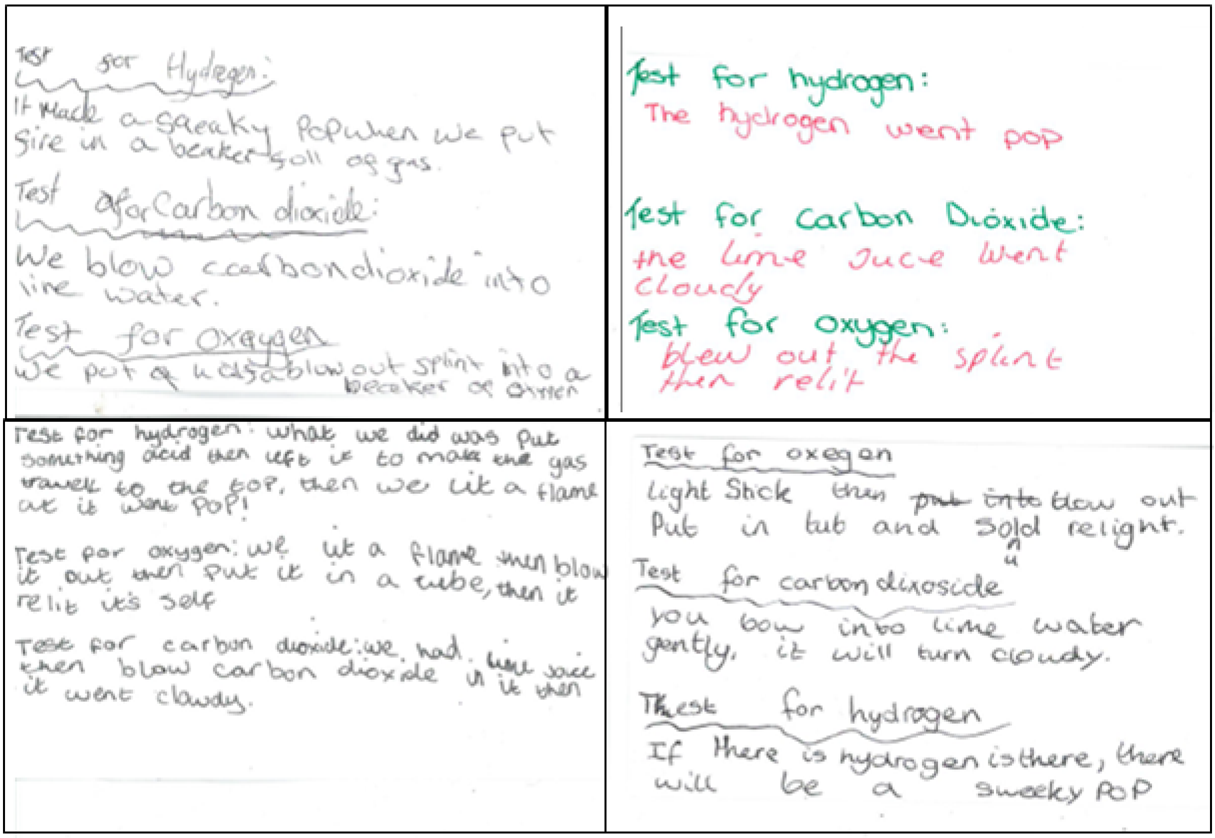
5) a) Complete the table:

	Carbon (C)	Hydrogen (H)	Oxygen (O)
Number of atoms in the reactants	1	4	4
Number of atoms in the products	1	4	4

5) b) What do you notice about the numbers in the table? Why do you think this is?
nothing new is made. no new particles are added. the same amount of things in the product
Excellent! ✓

Appendix 4

A sample of four exit cards completed by students at the end of lesson 4


Test for Hydrogen:
It made a sqeaky pop when we put fire in a beaker full of gas.
Test for Carbon dioxide:
We blow carbon dioxide into lime water.
Test for oxygen
We put a blow out splint into a beaker of oxygen

Test for hydrogen:
The hydrogen went pop
Test for carbon Dioxide:
the lime juce went cloudy
Test for oxygen:
blew out the splint then relit

Test for hydrogen: what we did was put something acid then left it to make the gas travell to the top, then we lit a flame an it went POP!
Test for oxygen: we lit a flame then blow it out then put it in a tube, then it relit it's self
Test for carbon dioxide: we had lime joice then blow carbon dioxide in it then it went cloudy.

Test for oxegen
Light stick then ~~put into~~ blow out Put in tub and sold relight.
Test for carbon dioxide
you bow into lime water gently, it will turn cloudy.
Test for hydrogen
If there is hydrogen is there, there will be a sweeky PoP

Appendix 5

Balancing equations worksheet

Students were asked to complete this during the lesson and it was marked to assess student understanding of balancing equations.

Balance the following chemical equations by adding a number (2 or more) where there is a gap marked by a line:

- The tables are there to help you count how many of each atom are in the reactants and products – **Remember** this will always be the same!
- **Remember:** you can only add big number in front of the chemical symbols – you cannot change the little numbers after the symbols!
- Try sketching atom drawings of the chemical reactions to help you.

1) 2 $H_2 + O_2 \rightarrow 2H_2O$

	Reactants	Products
H	4	4
O	2	2

2) 2 $Fe + O_2 \rightarrow 2Fe_2O_3$

	Reactants	Products
Fe	4	4
O	6	6

3) 2 $Cu + O_2 \rightarrow$ 2 CuO

	Reactants	Products
Cu		
O		

4) $C + O_2 \rightarrow CO_2$

	Reactants	Products
C	1	1
O	2	2

5) 2 $Mg + Cl_2 \rightarrow$ 2 $MgCl$

	Reactants	Products
Mg	2	2
Cl	2	2

Appendix 6

Student engagement tracker

Students were asked to complete the tracker at the end of each of the intervention lessons

Name:___________________						
Put a  in each box depending on how you felt at the end of the lesson						
Lesson number	1	2	3	4	5	6
My behaviour was right for learning						
I was on-task this lesson						
I was interested in this lesson						
I was focused on learning						
I put in a lot of effort						
I was willing to try the activities even if they were hard						
I put a lot of thought into the work I was doing						

Appendix 7

Engagement observation guidance table

This table was provided to the observing staff member that was present in each lesson
The staff member was asked to refer to the table to comment on the three aspects of student engagement exhibited in the lesson

During your observation, I would be grateful if you could please write a short comment under each of the follow headings regarding engagement. This could refer to the whole class but also individual students. I have provided some notes under each heading of what to look out for:
Behavioural engagement:
• Are students showing positive conduct and behaviour for learning? • Are they on-task and participating in learning activities? • Are they contributing to the flow of the lesson?
Emotional engagement:
• Do students' react positively or negatively to lesson activities? • Do students appear willing to engage in each learning activity? • Are students showing interest, enjoyment or enthusiasm? • Do any students appear bored?
Cognitive engagement:

• Are students showing more than just behavioural effort (just doing the work)?
  o Are they approaching work thoughtfully?
  o Are they focused on learning and mastering the scientific ideas?
  o Using metacognitive approaches to their learning?
• Are they willingly exerting the effort which is needed to comprehend the ideas present in the lesson?
• Are any students taking the initiative to search for further information?

Appendix 8

Focus group questionnaire

Students responded to these questions verbally in a group interview format in addition to written responses on individual sheets

Focus Group Questionnaire

1) What have you enjoyed most about these lessons on chemical reactions?

2) Think about a time when you were really interested, putting in a lot of effort and trying hard in one of my lessons – what made you do that?

3) Now think about any lesson when you weren't interested at all and didn't really try hard, you might even have been misbehaving. What made you do that?

4) A lot of the learning tasks I gave you included discussing a question or a task with your partner. Do you like talking about science with your partner? Do you think it helps you learn?

5) Do you think when I asked you questions you have to think about and discuss (like when I asked you to come up with the rules for writing chemical equations) it helped you to learn?