Towards a pedagogy of science teaching: An exploration of the impact of students-led questioning and feedback on the attainment of Key Stage 3 Science students in a UK school

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Abstract

This mixed method study investigated the extent to which the use of a model built around student-led questioning and feedback improved the learner engagement and attainment of a cohort of students. It compared outcomes from an experimental with a control group of students in Key-Stage 3 using a set of parameters. It found that the experimental group, who were taught using this model, showed improvements in engagement and attainment when compared to the control group. A model of discourse was proposed to help students take ownership of their learning and offered as a means of helping to transform science teachers' classroom pedagogy.

Keywords: questioning; feedback; science learning; constructivism; attainment; engagement; student-led learning

Introduction

When students are allowed to lead their own learning, they better understand and apply scientific concepts (Windale, 2010, Office for Standards in Education, Children's Services and Skills (Ofsted), 2013). Such an understanding improves their engagement and attainment (Nicol, 2007; Harlen, 2009). Hence, students are engaged in creating knowledge while working with other students (Parkinson, 2004; Adey & Serret, 2010). A constructionist framework promotes a student-generated inquiry and peer-collaboration approach which improves learning among science students (van Zee et al., 2000; Nuffield Foundation, 2013).

While science teachers embrace the principles of constructivism, many

lack opportunities for implementation (Savasci & Berlin 2012). This study is, therefore, designed to evaluate the effectiveness of a particular strategy, student-led questioning and feedback, in creating these opportunities. It investigates the extent to which student-led questioning and feedback can be used for promoting student-led learning and, therefore, improve the engagement and attainment of science students. It sets out to answer two questions: to what extent can student-led questioning and feedback be used to enhance students' engagement and attainment in Key Stage 3 science classrooms?; what are teachers' perceptions on the effectiveness of student-led questioning and feedback in engaging students in science? Through answering these questions, solutions might be offered for resolving the issue of promoting a fuller utilisation of the constructivist framework.

Models of effective learning discourse in the science classroom

Four models of interactive discourse between teachers and students are explicit in the literature. Model 1, Initiation, Response and Evaluation (IRE), involves the teacher initiating a question (I), the student responding (R) and the teacher making an evaluation (E) (see, e.g. Cazden, 2001, Mortimer and Scott, 2003). Model 2 involves a sequence of initiation, Response, Prompt, Response, Prompt, Response and Evaluation (I-R-P-R-P-R-E). The question is initiated by the teacher (I), the student responds (R), the teacher prompts (P) to generate further responses. The sequence is finally closed with an evaluation (E) by the teacher (See, e.g. Mortimer and Scott, 2003). Model 3 involves Initiation, Response, Prompt, Response, Prompt and Response (I-R-P-R-P-R). This is similar to model 2 but ends without teacher-evaluation (See, e.g. Scott, Mortimer & Aguiar, 2006). Lemke (1990) offers a fourth model which is essentially Question-and-Answer and involves students initiating the questions and teachers responding to them.

We offer a new and more effective form, model 5 (figure 1). This involves a sequence of Student initiation, Student response, Student probing and Student evaluation (SI-SR-SP-SE). Students initiate the questions and answers, give feedback to each other and evaluate the process. While teachers in science learning are presented as a facilitator and constructivist 'knowledgeable other' (Sundararajan, 2010), in developing this model, we extend the role of teachers beyond merely correcting misconceptions (Larkin, 2012 and 2017, Campbell, Schwarz &Windschitl, 2016). Focusing on correcting students' misconceptions can become detrimental to learning, as students are confused about why their ideas are not accepted, and this can limit their engagement with reasoning and idea revision (Campbell, Schwarz &Windschitl, 2016). Teachers should see and utilise misconceptions as a resource and should encourage trainee teachers to learn to 'incorporate their students' ideas into their instruction in ways that build upon those ideas' (Larkin, 2012, p 927). Classes in which teachers recognise the need for elicitation practices tend to thrive in science learning (Larkin, 2017).

The role of the teacher in this model is, therefore, similar to that proposed in Larkin (2017) which encourages teachers to ‘work on and with student ideas’ (Larkin, 2017, p 425 & Stroupe & Windschitl, 2015, p 181). The role of the teacher in model 5 is to ensure the utilisation of students’ ideas, including misconceptions gainfully, and help students create a model for self-correction of misconceptions.

At the heart of this model is the near-dominance of students in generating and responding to questions (Driver, Newton & Osborne, 2000; van Zee et al., 2001; Osborne and Patterson, 2011). This stands in contradistinction to Lemke’s model 4 in which students’ questions are followed by teachers’ answers, and to models one, two and three which are teacher-led. With model 5, students do the probing and evaluation, leading to the enhancement of their learning, as they can express their knowledge through conversations and sharing of ideas (Driver, Newton & Osborne, 2000; van Zee et. al; 2001) and presentation of outcomes from problem solving tasks (Sawyer, 2006).

It has the potential to promote and enhance Scientific reasoning and argumentation which are crucial elements of scientific learning (Fischer et al., 2014, Chinn & Clark, 2013). This resonates withToulmin’s (1962) original argumentation model with its emphasis on backings, evidence and refutations. While reasoning is an important tool for activating learners’ sense-making and cognitive comprehension (Larkin, 2017), argumentation is an essential skill for enabling science learners to justify their claims and challenge others’ claims (Weinberger, Stegmann, & Fischer, 2010). The dominance of students’questions in this model promotes sense-making for both student questioners and respondents. The process of developing and responding to questions draws on an ‘advanced meta-conceptual understanding of science’ (Bullock, Sodian, & Koerber, 2009) thus facilitating the advancement of meta-cognitive understanding. Because argumentation relates to the learning of core content and acquisition of general argumentation skills (Chinn & Clark, 2013), it becomes inevitable that the predominance of students' questioning and answers will facilitate the process of developing the required skills for general argumentation (Toulmin, 1962). Responding to questions requires a process of acceptance and rebuttal which are essentially integral to the development of argumentation skills.

Methodology

This study was inspired by a constructivist approach to learning (Creswell 2012; Savasci & Berlin, 2012). It employed three techniques; observations and field notes, interviews and the analysis of performance scores which combined to further the course of triangulation to ensure the reliability and validity of the findings (Newby, 2010).

The research participants

The study involved 161 mixed-ability Key Stage 3 students (13 years old students in year 8, the second year of secondary education in England) in a co-educational school. The students were classified into two groups informed by their teachers' willingness to participate. The experimental group consisted of 52 students of mixed abilities and gender split into two class cohorts, while the control group had 109 mixed-ability students split into 5 class cohorts. Both groups had comparable achievement backgrounds and similar attainment patterns, as shown through a pre-intervention assessment. A pre-intervention test was administered to both groups. The result (see table 1) shows a similar performance pattern. In the school, allocation to classes draws on a framework that allocates a balance of ability levels to each class thus ensuring that all classes had a similar pattern of representation of various ability levels.

The research

The research was designed as a quasi-experimental study to facilitate testing for a nomothetic causal relationship (Check & Schutt, 2012). This allowed us to avoid the potential influence that pre-existing differences between the groups might have on the findings. In using the quasi-experimental design, we were conscious of the need for a level of control, which is sometimes not 'achievable outside of a laboratory' (Check & Schutt, 2012, p246). In response to this, we ensured that all controllable variables such as lesson content, assessment tasks, as well as teachers remained consistent.

Students in both the experimental and control groups were given problem-solving tasks in groups, to research and locate information from textbooks, exercise books, internet resources and previous homework tasks (Cowie, Jones & Otrel-Cass, 2011). The problem-solving tasks were based on the topic 'Food and Glorious Food', selected from the English National Science curriculum.

Students in the experimental group were trained to use Bloom's taxonomy by their teachers, who had been previously trained, over two 50-minutes sessions. Teachers modelled various types of questions to the students from low (e.g. knowledge questions) to high order questions (e.g. evaluation questions), and students were given the opportunity to locate these question types within their epistemological framework for learning (Elby & Hammer, 2010). Such prompts include; such as what; why; can you define; what would happen if; judge the value of; justify (Bergman, 2009). Subsequent lessons were delivered using this model. Teaching and learning in the control groups followed a traditional process in which teachers utilised the transmission of knowledge approach (van Zee et al., 2001) which resonates with the IRE model.

After seven weeks, all the students in the year-group were required to make presentations. Presentations were graded using a set of success criteria (See table 5) provided by Ontario School Library Association (2012) (OSLA) which has been successfully used to help students engage in quality interactions, feedback and communicate scientific ideas with others (Magaji, 2016).

Lessons were observed over a period of seven weeks by the researchers while the teachers kept reflective notes. The researchers met regularly with the teachers to discuss their experience in the lesson observations and how grades were awarded to students. This promoted validity and reliability of the data collected, as a consensus was achieved each time. The observed lessons were audio recorded to permit subsequent reviews.

Teachers now recognise that misconceptions could be a reflection of students' epistemologies (Larkin, 2012, Elby & Hammer, 2010), and that they can initiate sensemaking talk during whole-class discussions. Their focus was to elicitate ideas and to prompt students to track the link to real-life situations (Campbell, Schwarz & Windschitl, 2016), thus aligning with model 5. Teachers only engaged in correcting misconceptions when necessary using comments such as; "could someone respond to that", "do you have any alternative explanations to that", "what do you think", to challenge ideas and promote active reasoning, rather than presenting a scenario of corrections. This promoted the review of epistemological resources and epistemological framing (Elby & Hammer, 2010) which enabled students to concretise knowledge variables. Teachers were, therefore, not only concerned with the content that students learn but also in how they organise and identify knowledge.

Data collection

Data were collected from lesson observations, field notes from teachers, semi-structured interviews, and test results (See table 2). Tests, which were administered pre- and post-intervention, was produced by the borough's education authority and has been consistently reviewed and used for over five years. It is currently used in all the twenty schools in the borough. The findings from the lesson observations partly informed interview questions. This sequential structure enhanced the validity and reliability of the data (Arksey & Knight, 1999).

Data Analysis

Analyses of data were carried out sequentially. The audio-recordings were transcribed and content analysis was used to identify patterns and categories within the text (Cohen et al., 2007; Gray, 2009). NVIVO 10 was used to analyse the emergent categories (Penna, 2013). Related concepts and terms were identified so that factors such as questioning and feedback; clarity; probing and analysing others' views; and problem-solving were classified as elements of structured classroom interaction/discourse with questioning and feedback central to this process.

The interview questions sought the views of teachers on the effectiveness of using questioning and feedback as teaching strategies and the potential impact on their students' learning. So, although the questions started with 'what' and 'why' words, participants were given free rein to introduce different dimensions to the discussion. The data was exhaustively analysed, following which a descriptive code for each piece of datum was generated (Cohen, Manion and Morrison, 2007). The codes were created around patterns and themes established through simple semantic denotations and connotations. We enhanced the reliability of our coding through discussions with the teachers. We noted the frequency of codes developed in each category (Creswell, 2012; Denzin & Lincoln, 2013) in order to show the distributional pattern of students' engagement.

Test scores were converted into the current Progress 8 and attainment 8 grading systems in the English National curriculum (Department for Education (DFE), 2016). This was based on using grade boundaries from standardised tests. The grade boundaries used varies from 0-100%. Attainment of students in England was previously measured using levels. However, since 2014, this has changed with more focus on assessment without levels (Earl & Davies, 2014).

Findings

Findings from the data collected are presented in the context of the research questions. The first research question is "To what extent can the use of student-led questioning and feedback enhance students' engagement and attainment in Key Stage 3 science classrooms?".

Findings from lesson observation

By weeks 5 and 6, students in the experimental groups had made significant progress. They were actively engaged in questioning and feedback and shared ideas through which they enhanced knowledge development. Two dialogue scenarios from students' interaction are presented below as illustrations of their progressive enhanced engagement.

Findings: Illustration 1a – Week 1

The illustration presented here is an excerpt taken from week 1 of the project. It shows that the students predominantly used simple questions usually directed at their teachers. The dialogue below illustrates the contribution and participation levels of the students at this stage.

Teacher: "What do nutrients do to our body?

Student 1: Excuse me, but what do you mean by nutrients

(Teacher was silent for some time and so were the students)

Teacher: Can anyone tell us what nutrients are?

Student 3: I think they are things in our food that help us to grow and be healthy.

Teacher: Thank you. What more can we add?

Teacher: Are all nutrients the same?

Teacher: Nutrients are different and play different roles in our body. For example, carbohydrates help us to .....

(The dialogue peters out and the teacher was bombarded with questions that he kept providing one-off answers to).

Findings: Illustration 1b – week 5

Student 1: You said that carbohydrates are really good for your body but what will happen to your body if you ate too much of it and not mixing with other foods in the correct quantity? [*Question and probing*]

Teacher: please use words like the right proportions, amounts and balanced diets in your discussions. [Facilitating]

Student 2: You will get fatter because the carbohydrate contains high calorie as well. For example most people dieting, take low carb diets in small portion because carbohydrates have more calories in them. I have seen people that I know that are dieting and they eat less [Response and feedback]

Student 3: I agree and have a good example to share. You will get fat because you are eating only one type of food, do you watch super skinny versus super fat on TV, the people who are fat ate foods high in fats and carbohydrates and they are told to diet. Some of the skinny *people ate one type of food like chocolate and fats but still remain skinny but I don't think they are healthy as one of the girls have that sickness that starts with ano… I can't remember the name again [Feedback and evaluation].*

Teacher: do you mean anorexia? [Facilitating/ more knowledgeable other]

Student 3: Yes miss that is the name they called on TV [confirmation]

Student 4: And you said they are healthy but how can a food that is healthy be bad for your body? How do the fats actually become fat in someone's body? Can you justify this? [Probing]

Student 5: Yes they are all healthy as long as you use the energy of the carbohydrate and also eat a balanced diet. Like having small proportions of different foods. If you do not use them, the energy will be stored as fat which is bad for you because they have high calories [Response and feedback]

Student 6: I know what you can do, you can use the energy by doing exercise and keeping fit so that it does not build up in your body for example athletes burn a lot of energy from the food they eat to keep them fit [Response and feedback]

Student 7: Can I comment on that? Please let me explain it better. For example if I am an energetic person and my body is used to being active and later I become lazy and I still eat like I do, the fat will start building up in my body because fat is energy. If I don't use the energy it will run out and the fat remains in me [Feedback and evaluation]

Illustration 2: week 6

Student 1 question: What would happen if you don't *have your five a day?* [*Question*]

Student 2: *You wouldn't get enough nutrients and vitamins and so, you would have an unhealthy diet because it will not be a balanced diet [Response]*

Student 3: Can I ask her about the last thing we discussed about diabetes as we are talking about food now? You see the way you said type 2 diabetes, I am not sure what you meant and how do people get it? [Probing]

Student 4: Let me answer him, oh it's like when you have too much sugar in your body [*Response*]

Student 3: *Oh yes what are the other types?* [*Question*]

Student 5: *Type 1 is the other one- yes, yes may be serious than type 2 [Response]*

Student 6 question: Can you defend your position about what you said on type 2 diabetes, you said that people have too much sugar in their body to have it but if you are obese you are fat and is it because of the sugar or something different? [*Question and probing*]

Student 7 response: *Yes, there are different types, type 1 would be where you have high sugar and your blood just got too much sugar and this can affect your health [Feedback]*

Student 8: Yes, but if you are obese you may have diabetes but I don't know which one it is [Response]

Teacher: *You have not learned this topic but you have contributed some knowledge maybe we can move onto something else [Facilitating/ knowledgeable other]*

Student 8: *Miss, I like to try again as I have some information now to help me answer the question on diabetes*

Student 8 feedback: I don't know the difference but when you have type 1 diabetes you have to have injections every day to help your glucose level, type 2 is not as serious and you can have tablets to help you. I have seen where someone is given the injection to help him [Feedback and evaluation]

Teacher: Type 1 diabetes, if you are born as a child and you don't produce this chemical called insulin which is a hormone and what it does is, it tells your body that you are carrying too much sugar in your blood and you need to store it or use it up. So, type 1 diabetes is called juvenile diabetes- because children have it. They will be given injections of insulin throughout the day and that would affect their blood glucose levels. Type 2, because of your diet you develop resistance to insulin and so, your insulin doesn't work anymore. You need to control this by having a healthy diet [Facilitating]

Findings from the end of unit test scores

Data were collected through an analysis of test scores (from standardised tests) and converted to progress 8 and attainment eight scores (see table 2) in line with current assessment framework in England (DFE, 2016). A mixed factor ANOVA was performed on the data whereby pre/post scores were compared as a repeated measure, across the two experimental conditions, (intervention/control). Table 3 shows that the analysis revealed significant main effects for both the group, ($F(1,159)=194.92$, $p<0.001$) and the test, ($F(1, 159)= 331.04$, $p<0.001$), as well as a significant interaction ($F(1,159)= 647.31$, $p<0.001$). To further understand this interaction, t-tests were performed to discern the simple effects of the study. This further analysis revealed a significant drop in performance for the control group, ($t(108)=6.84$, $p<0.001$), and a significant improvement for the experimental group following

Findings from students' presentations in lessons

Students' presentations were scored on a scale of 1 – 5 based on the use of success criteria. Table 5 shows that, for the experimental group, the majority of the students (98%) achieved between outstanding (grade1) and satisfactory (grade 3). Only one student (2%) was graded as needing improvement (grade 4). With the control group, the majority of the students (105, 96.3%) achieved poor (grade 5) and needing improvement (grade 4). Only four students (3.7%) achieved grade 3, satisfactory. No student achieved outstanding (grade1) or good (grade 2). In addition, the students were also assessed on their ability to contribute to the learning process through asking questions and providing feedback to their peers. This is a regular activity carried out by their teachers in response to the Ofsted requirement for 'scientific communication and promoting curiosity'. Since 2013, Ofsted had included the criterion of science communication and promoting curiosity as a measure of success in science teaching. Teachers in the UK have responded to this by monitoring students' classroom contributions regarding answering questions and providing feedback to their peers. We analysed the grades awarded to both the experimental and control groups. The result for the experimental group showed improvement in this aspect with 90.4% of the students achieving between outstanding (grade 1) to satisfactory (grade 3) while all the students in the control group (100%) were considered poor (grade 5).

Findings from the analysis of interview data

To explore our second research question, we analysed the transcripts of interviews of two teachers, who taught the experimental groups and were involved in the lesson observations. The interview analysis presented in table 4 shows that structured classroom interactions/discourses with a frequency score of 110, scored highest as the preferred form of students' engagement while good behaviour with a score of 2 was lowest.

the intervention, ($t(51)=23.45$, $p<0.001$).

A number of themes emerged from the interviews. First, student-led questioning and feedback can serve as a primer for self-regulated learning. One of the interviewees noted:

> *"When students are regularly allowed to develop their own questions and give feedback to each other in lessons, this will improve their engagement and develop their thinking skills in science and this is what I have experienced working with the students in this project".*

Second, features such as questioning and feedback; clarity; probing and analysing others' views; and problem-solving which we classified as elements of structured classroom interaction /discourse were identified as outcomes of using questioning and feedback and fit in with model 5's concept of student-led initiation of questions, response, probing and evaluating feedback.

Other key areas/codes identified was motivation. Students motivate each other and demonstrate the willingness to complete and engage in the discourse (see table 4) for a sustained period. One of the interviewees commented:

> *"As each group presented their work, this further enhanced the progress of other students to be more involved especially those not serious initially and lots of them realised they could get more out of the activities".*

Interviewees also identified the use of prior knowledge, which links outside classroom experience to the problem under investigation. Finally, the theme of promotion of good behaviour was identified. One interviewee noted

> "*Especially looking at this activity students were constantly having to be aware and thinking. It was not like they could switch off for a while. They were not being disruptive, they were all working, but in a normal lesson most of them would be totally disengaged, but in this project it was different*

> *because they were processing information constantly and they knew they would be asked questions and may be required to answer them. This made them to be on task completely and with full attention*

Discussion

Lesson observation: Discussion

The teacher's role in dialogue 1a conflicts with the principles of science teaching proposed in Larkin, (2012 & 2017). There were no opportunities for students to build upon their ideas, as the teacher is mostly involved in the process of correcting students' misconceptions rather than eliciting their ideas in detail. Students at this stage appeared to rely mostly on the teacher for information. Students' misconceptions were not utilised as resources for learning (Larkin, 2012) and knowledge is absorbed from an authoritative source (Elby and Hammer, 2010). On the one occasion they ventured into asking questions, it was structured in a way that required simple information. This cannot facilitate the acquisition of complex and deep knowledge.

In contrast, the excerpt in illustration 1b shows an interactive session with students questioning, probing and providing feedback. Unlike the excerpt from week 1a, initiation questions were used by the students, and they invariably led to knowledge expansion and validation. For example, when student 1 said, "*You said that carbohydrates are really good for your body but what will happen to your body if you ate too much of it and not mixing with other foods in the correct quantity",*

what the student has done is to initiate a new dimension of deeper level of learning moving from ordinarily looking at the features of carbohydrates to the impact they could have. This is arguably a precursor to the students' development of argumentation skills which are enhanced by the ability to make claims, offer evidence and make refutations (Toulmin 1962 and Weinberger, Stegmann, & Fischer, 2010).

Further, the complexity predicted in this contribution is embodied in the use of the coordinator "but" which is usually used to combine ideas (Seely, 2013). It is within this complexity that further learning beyond the simple surface level knowledge is embedded. It reflects the initiation component of model 5 (figure 1) leading to responses from students 2 and 3 which reflect a commensurate depth and complexity of knowledge. As evidence of deeper learning, we note that the students proceeded to analyse the problem and contextualise it in real-life situations. Carrying out an analysis involves a process of finding merits and demerits- making a case for and against a taken position. In such an analysis, the development of reasoning and argumentation skills becomes inevitable (Toulmin, 1962, Fischer et al., 2014; Larkin, 2017). Further, students would need to have classified the content they are studying through the prism of their cognitive understanding. Executing this would have involved the development and utilisation of both their reasoning and argumentation skills. This process illustrates the response component in model 5 with students using real-life experience to exemplify their understanding of issues around carbohydrates and fats. It also shows the potential connectedness between student experiences and the intended content understandings' (Larkin, 2017, p 436). This is a desired outcome which makes the lesson student-centred, as proposed in model 5.

We also see that probing is an ongoing process in this lesson. As students learned more/ validate their knowledge, they tended to probe further. For example, when student 4 noted "A*nd you said they are healthy but how can a food that is healthy be bad for your body? How do the fats actually become fat in someone's body? Can you justify this?'* This probing input generated a dialogue leading to deeper learning. In addition, feedback is provided as illustrated by students 5, 6 and seven who offered feedback involving elements of evaluation. This is particularly evident in the contribution of student 7. The subsequent feedback and evaluation all led to deeper and more complex knowledge, all of which were generated with little input from the teacher. This reflects the emphasis placed on students' dominance in the learning process in model 5. These exchanges and interactions echo the concepts of claims, warrants, backings, evidence and refutations highlighted in Toulmins (1962). In addition, it highlights the teacher's ability to create an opportunity for students to express and develop their ideas (Larkin, 2012; 2017) and to know that "knowledge can be constructed rather than propagated, that is passed on from teachers to students" (Elby and Hammer, 2010, p411). Such a strategy helps to avoid a "transmissionist" (Elby and Hammer, 2010, p 412) and "delivery pedagogy" (Stroupe, 2016, p52).

As outlined in model 5, student 1 in illustration 1b initiated the learning journey with the question, "*What would happen if you* don't *have your five a day?"* This is a form of probing which invites an answer that goes beyond the surface level with the use of the subordinator/ conditional, 'if'. It attracted a response from student 2 which goes beyond mere generalisations to extend to an analysis of potential deficiencies that may be associated with such a diet. Even more interesting is the link that student 3 drew between the group's previous dialogues and what might be seen as new learning. In a way, this amounts to a form of knowledge validation and construction as opposed to propagated or transmissionist knowledge from teacher to students (Elby and Hammer, 2010). Student 3 extrapolated from the current dialogue and linked it to diabetes through a process of probing. This is an indication of a deeper level of learning which resulted in further probing and questioning by student 6. This dialogue shows that, although the students were rather unclear about the differences between both types of diabetes, student 8's feedback and evaluation of his understanding of the concept through real life and everyday experiences (Campbell, Christina and Windschitl, 2016; Golabek and Amrane-Cooper, 2013) contributed to clarification and validation of knowledge.

Deeper learning was most facilitated through evaluation provided by student 8, who summed up the learning achieved in the course of the dialogue with "*I don't know the difference but when you have type 1 diabetes you have to have injections every day to help your glucose level type 2 is not as serious and you can have tablets to help you.*

We also see what might be termed the inevitability of the teacher functioning as a knowledgeable other on rare occasions. In the excerpt, the teacher's intervention in re-defining diabetes types echoes Wiliam (2011), who argues that the teachers' role is necessary to close gaps in students' knowledge when immediate feedback appears to be most helpful, and the task well beyond the learner's capability. Nonetheless, the intervention in this context merely sets the scene for further probing and the associated deeper learning such probing attract.

The two examples of students' dialogue demonstrate how students can sustain classroom dialogue with little teacher-intervention by using features of model 5 with the teacher encouraging students to express their ideas (Campbell et al., 2016, Larkin, 2012, 2017) and construct knowledge, as evidenced in the range of specific outcomes. Although there were occasional teacher-interventions reflecting the notion of knowledgeable other (Sundararajan, 2010; van Zee et al., 2001; Nuffield Foundation, 2013), the students controlled the process. Questioning, response, probing, feedback and evaluation sequences, as shown here, resonate with the framework of model 5. They particularly align with the key features of student- leadership and autonomy (Kiemer, Groschner, Pehmer & Siedel, 2014), information synthesis (Maskiewicz & Winters, 2012), co-construction of knowledge, discussing and challenging views, and above all, collaborating with other students to explore ideas (van Zee et. al., 2001; Adey & Serret, 2010) in a constructive learning environment.

The duration of the audio recordings of the discourse events during the lessons signify the enduring nature of the students' engagement (Fielding-Wells and Makar; 2008; Newton and Newton, 2011) and shows how they created knowledge and shared ideas (van Zee et al., 2001; Nuffield Foundation) in a supportive learning environment. By assigning roles to each other, they take ownership of their learning (Blanchard, 2008; Cowie et al., 2011) in a way that encourages student talk in lessons (See, e.g. Hog, 2010; Waind, Robotham & McGregor, 2012; Aguiar, Mortimer & Scott, 2010).

Drawing on the foregoing, we suggest that the use of model 5 discourse is responsible for the improved attainment and crucial outcomes such as effective feedback, evaluation and validation of knowledge and autonomous learning (Min (2008). Students were inclined to independently search for answers even when their teachers attempted to intervene as shown in the dialogue on 'diabetes'. It is, therefore, important that science teachers encourage students to draw from their out-of-classroom experience and knowledge (Cowie et. al., 2011) and apply these to their discussions.

Discussion: end of unit test

Evidence from the analysis of pre and post-test scores (table 2) shows that it is probable that the intervention administered to the experimental group enhanced their cognitive ability (Chin, 2006; Hogg, 2010). This might have been facilitated by their improved ability to construct knowledge (Chin, 2006; van Zee et al., 2001; Sampson & Blanchard, 2012). It might also be that, because the intervention promoted the consistent and sustained use of high order questions, engaging with and generating responses to similar types of high order questions had become easier.

Discussion: students' presentations

The grades achieved by the two groups indicate that the students in the experimental group have made more progress. Given that the two groups started from a common attainment level, it is probable that the intervention is responsible. The findings make a further case for model 5 as a science pedagogy. Central to this is the demonstrable ability of students to ask and respond to questions, probe each other's views, evaluate feedback and ultimately enhance deeper learning. As this study has shown that student-student interactions in lessons through questioning and feedback (Alexander, 2008; Swaffield, 2008), using model 5 deserves to be considered as a viable tool for promoting students' engagement in science classes.

In response to the first research question, therefore, there is evidence that students were more engaged in the problem-solving tasks, as demonstrated through the development of quality questions and feedback, an improved level of interaction between students and their teachers, and better test achievement. There is, therefore, evidence that the use of model 5 appears to be an influential factor in students' learning and achievement.

Discussion: interview data

Structured classroom interaction/discourse was rated higher than other forms of classroom engagement in learning. Features of engagement such as questioning and feedback; clarity; probing and analysing others' views; and problem-solving were grouped in this category. Interviewees felt that students were able to relate to their real-life situations because the activity created a platform that enhanced interactions. This, potentially, helped to promote students' understanding of the Nature of Science that they can apply to other situations (Grime, 2012; Golabek & Amrane-Cooper, 2013). In addition, the students were able to apply what they know from previous experiences and contribute to knowledge generation (Cowie, Jones & Otrel-Cass, 2011; Mishra, 2014).

The knowledge of real-life situations is a form of cultural capital that students bring into their classroom discourse which can improve their attainment (Winkle-Wagner, 2010). Such interaction is facilitated by model 5 and can help to convert any underlying misconceptions into resources (Taber, 2010, Larkin 2012 & 2017). Also, it can simultaneously develop their current and previous knowledge in order to improve their engagement with scientific processes.

Limitations

As with every experimental research, this study has limitations that might temper the universality of our findings. These limitations stem from the inputs and processes of the research. The first relates to the duration of the intervention and subsequent observations. Could the study have produced more significant gains if the intervention had extended beyond seven weeks? According to Schanzenbach (2012), this is a possibility, as programmes can improve their effectiveness over time.

Another source of limitation is the rather small number of teachers and the differences between teachers in the experimental and control groups. Two teachers' views appear to be rather limited, and it is possible that there might be variations to these views if the numbers had increased. Also, there is no way of knowing whether the differences between the various teachers involved with different groups is significant. These factors temper the claims that might be made in respect of our findings.

Nonetheless, we are confident that the study as implemented has given us a significant indication of how the approach we have investigated might work effectively. Subsequent researchers could factor in the limitations identified above in planning future research.

Conclusion

While teachers' dominance of classroom discourse is often criticised (Van Dijk, 2001; Chin, 2006; Reinsvold & Cochran, 2012), a pertinent but seldom addressed issue is how to promote this engagement. This study has shown the potential of using model 5 as a tool for constructive learning to achieve this goal. It provides the opportunity for students to lead their own learning by developing questions and probing each other, giving feedback to peers and evaluating other students' responses. In contrast, the existing models do not provide such an opportunity.

One of the features of the lessons we observed for the experimental group was the recognition of the student's voice. There was evidence of a degree of flexibility in planning the lessons which allowed the students to have a choice in their own assessment. This gave them greater autonomy over their learning (Darlington, 2012), even though it was facilitated by the teachers, who recognise the importance of eliciting students' ideas (Larkin, 2012, 2017) in facilitating the construction of their own knowledge. The ability to create such flexibility can and should, therefore, be an area for professional development of science teachers. Acquiring such flexibility skills will enable them to create a discourse environment for students (Driver, Newton & Osborne, 2000; Maskiewicz & Winters, 2012; Nuffield Foundation, 2013), promote learning in science, and deeper understanding of scientific phenomena.

In this study, model 5 encourages a deeper level of engagement, and, as a corollary, deeper learning on the part of the students. In this study, engagement with model 5 positively modified and improved students' attitude to learning leading to the development of autonomy over their learning, as their teachers were not sole decision-makers. From a social interactionist perspective, this eliminated any form of social power relationships (Van Dijk, 2001; Reinsvold & Cochran, 2012) associated with the normal forms of interactions in the traditional classroom that are usually dominated by the teacher.

For us, model 5 has the potential for utilising constructivism in science classrooms, as it supports a student-generated inquiry and peer collaboration approach to learning and other forms of interactions that can improve scientific reasoning and literacy. Although model 5 can promote student initiation of questioning, student response, student probing and student evaluation, realising its full potential is significantly dependent on, and informed by, the quality of questioning and feedback. In essence, while the use of the model in itself might be seen as a necessary condition, sufficiency comes with the questioning skills of students, which ultimately structures the model of discourse utilised in their classroom.

(8384 words including figure, tables and references)

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Table 1

Frequency of control and experimental group students per attainment banding pre-intervention

Attainment grade	Control group (n)	Experimental group (n)
1 (G)	0	0
2 (F)	0	0
3 (E)	14	8
4 (D)	68	26
5 (C)	26	17
6 (B)	1	1
7 (A)	0	0
8 (A*)	0	0

Table 2

Frequency of experimental and control group students post-intervention

Attainment grade	Experimental group (n)	Control group (n)
1	0	0
2	0	8
3	0	34
4	0	55
5	2	12
6	19	0
7	23	0
8	8	0

Table 3

Descriptive and test statistics for control and experimental groups.

	Control group		Experimental		Total	
	Pre	Post	Pre	Post	Pre	Post
M	4.08	3.65	4.11	6.71	4.09	4.64
SD	.67	.77	.81	.78	.7 1	1.63
n	109	109	52	52	161	161

Note. Mixed factor ANOVA with pre/post scores as a repeated measure across the two experimental conditions revealed significant main effects for both group, ($F(1,159)=194.92$, $p<0.001$) and the test, ($F(1, 159)= 331.04$, $p<0.001$), as well as a significant interaction ($F(1,159)= 647.31$, $p<0.001$). T-tests revealed a significant drop in performance for the control group, ($t(108)=6.84$, $p<0.001$), and improvement for the experimental group following the intervention, ($t(51)=23.45$, $p<0.001$).

Table 4

Frequency of key areas from interview analysis

Key areas	n
Prior knowledge	25
Thinking skills/cognitive and metacognitive development	15
Structured class room interaction/discourse	110
Good behaviour	2
Planning resources	3
Facilitating learning	4

Table 5

Frequency and percentage of grades/scores from students' presentations, questions and feedback

Grading (scores)	Number of students and percentage meeting all criteria on students' presentations n (% of students)		Number of students and percentage meeting criteria on developing questions, answering/feedback n (% of students)	
	Exp	Con	Exp	Cont
Outstanding (1)	6 (11.5%)	0 (0%)	4 (7.7%)	0 (0%)
Good (2)	25 (48%)	0 (0%)	14 (26.9%)	0 (0%)
Satisfactory (3)	20 (38.5%)	4 (3.7%)	29 (55.8%)	0 (0%)
Needing improvement (4)	1 (2%)	8 (7.3%)	5 (9.6%)	0 (0%)
Poor (5)	0 (0%)	97 (89%)	0 (0%)	109(100%)