UNIVERSITY OF CAMBRIDGE
Faculty of Education

*ISSN 2043-8338*

*Journal of Trainee Teacher Education Research*

**JoTTER: Volume 1 (2010)**

# A critical analysis of how focussing lessons on *How Science Works* affects learning and motivation in year 10 lessons on *space*: an action research project.

**Simeon K Dry**

(PGCE Physics, 2008-9)

simeonkdry@gmail.com

## Abstract

*An action research project has been carried out to investigate the effect of focussing on How Science Works in a sequence of six mixed-ability year 10 physics lessons in a comprehensive school in England. The How Science Works material was illustrated using material about space. The effect of this approach on students' learning of How Science Works and space was considered, as well as its effect on students' motivation. Data from test results, questionnaires and interviews collected before and after the intervention revealed a significant degree of polarisation in the attitudes of the class, but indicated that students' knowledge of How Science Works had noticeably improved following the intervention. However, it appears that the sequence of lessons was not successful in teaching the students the space material*

# A critical analysis of how focussing lessons on How Science Works affects learning and motivation in year 10 lessons on space: an action research project.

**Simeon K Dry**

## Introduction

Many science educators would consider that it is important that students of science do not only learn the details of various scientific topics, but also learn something of the nature of science, or '*How Science Works*' (HSW). For many teenage science students, this will be of greater value to them in later life than the scientific content itself, especially if they wish to be responsible citizens in a twenty-first century democracy (Millar and Osborne 1998; Albe 2008).

There are various possible approaches to teaching HSW. One such approach is to teach a traditional scientific-content-based syllabus whilst looking for opportunities to teach aspects of HSW. In this study, I shall investigate the effect of doing the opposite: focussing lessons on HSW, and using other scientific content to illustrate various aspects of the nature of science.

## Literature Review

In this section I shall review some of the existing literature relevant to this study, focussing on four particular areas: the nature of action research, the HSW learning demand, possible approaches to teaching HSW and the methodologies of previous studies.

### Action Research

I shall begin by considering the nature of action research, and the extent to which this intervention can be considered to be an action research project. Action research is a strategy for social research in which practitioners research the effects of changing an aspect of their practice (Denscombe 2007). Denscombe identifies four characteristics of action research. Firstly, he identifies action research as dealing with practical issues or problems, a characteristic which is clearly true of this intervention, since the teaching of HSW is a real task faced by all science teachers. Secondly, Denscombe highlights that the effecting of change, not only the study of current practice, is inherent in action research. This is also true of this intervention. Thirdly, Denscombe identifies that an action research project involves the active participation of practitioners, which is the case in this study, since the present author was not only the researcher, but also the practitioner responsible for teaching the class involved in the intervention.

Denscombe's other characteristic of action research is that it is cyclical, involving

> "a feedback loop in which initial findings generate possibilities for change which are then implemented and evaluated as a prelude to further investigation" (p. 123).

This characteristic is barely true of this study. Information gained from pre-intervention questionnaires did slightly influence the teaching about the role of the scientific community, but the findings of the research have not been used to influence further intervention. According to Denscombe, this is not uncommon: "in reality, action research often limits itself to discrete, one-off pieces of research" (p. 125).

Somekh (1995) says that "[action research] may be instigated by an individual, but its momentum is towards collaboration" (p. 342). Collaboration with colleagues was not explicitly built into this study.

Denscombe (2007) identifies three approaches to action research, distinguished by the level of change the intervention is designed to effect. Technical action research aims to improve practice. Practical action research aims to also develop the professional understanding of the practitioner(s) involved. Emancipating action research seeks to change the parameters imposed by a system or organisation, rather than just reforming practice within those parameters. This intervention is not emancipating, as its aim is to investigate the implementation of a pre-existent requirement of English science education – that children should be taught about HSW. The distinction between technical and practical action research is almost non-existent in the present case where the researcher is also the practitioner, since change in practice will only come about as a result of an understanding on the part of the researcher-practitioner. So this project may be described as practical action research.

## How Science Works Learning Demand

I shall now consider the concepts and learning demands associated with HSW that other authors have identified or investigated. These formed the basis for the HSW content of the teaching sequence. I have grouped them here under four headings.

### The Purpose of Science

Driver, Leach, Millar and Scott (1996) investigated students' ideas about a number of aspects of the nature of science. Their first research question concerned the purpose of science: "What do students see as characterizing the kinds of questions which scientists address?" (p. 60).

### The Nature of Scientific Knowledge

Driver et. al. (1996) also investigated a number of aspects of the nature of scientific knowledge, including the purpose of experimentation, and the nature and evaluation of theories. Some would consider such aspects of HSW to be an important part of science education, as suggested by Millar and Osborne (1998) in a significant report entitled *Beyond 2000*. Their conclusions are based on discussions at a number of seminars and open meetings, rather than being justified with classroom-based evidence. However, a large number of people were involved in these discussions – 180 or more, including "approximately twenty leading individuals working in science education in the UK" (p. 2032). This suggests that their conclusions may represent a well-informed and well-balanced point of view, if there was sufficient variety in the attendees of the meetings.

Millar and Osborne suggest that students ought to learn that "many scientific explanations are in the form of 'models' of what we think may be happening, on a level which is not directly observable" (p. 2021). Harrison and Treagust (2000) agree that "model-based thinking is a sophisticated process that should be an explicit part of learning in science" (p. 1011). They cite Grosslight, Unger, Jay and Smith's findings that secondary students tend to see models as corresponding directly to the real world, and being completely correct (Grosslight et. al. 1991 cited in Harrison and Treagust 2000), rather than being a tool for exploring ideas. Harrison and Treagust argue that consequently, students do not respond well to being presented with multiple models for the same concept.

Abd-El-Khalick, Bell and Lederman (1998) identify a number of aspects of HSW that they say are accessible and relevant to primary and secondary students. One of these is that science is "subjective (theory-laden)" (p. 418), rather than being as objective as is sometimes portrayed. Abd-El-Khalick et. al. also list the idea that "scientific knowledge is tentative (subject to change)" (p. 418). Millar and Osborne (1998) agree that students should

> "appreciate that many things which we would like to understand cannot (yet) be explained fully in terms of a predictive theoretical model" (p. 2022) and that "evidence is often uncertain and does not point conclusively to any single explanation" (p. 2022).

## The Role of Scientific Evidence

Abd-El-Khalick et. al. (1998) identify the role of scientific evidence as a concept that can be taught. They include the fact that science is empirically based and also highlight the importance of the distinctions between observations and inferences and between theories and laws: "…laws are statements or descriptions of discernible patterns in observable phenomena, and…theories are inferred explanations for those phenomena" (p. 425).

Millar and Osborne (1998) also suggest teaching that "if an explanation predicts an event which would otherwise be unexpected, and this is then observed, this greatly increases our confidence in the explanation" (p. 2022).

## The Scientific Process

Abd-El-Khalick et. al. (1998) point out that science is "partly the product of human inference, imagination, and creativity" (p. 418; see also Millar and Osborne 1998). Millar and Osborne (1998) suggest teaching that "any reported scientific findings, or proposed explanations, must withstand critical scrutiny by other scientists working in the same field, before being accepted as scientific knowledge" and that "new ideas often meet opposition from other individuals and groups, sometimes because of wider social, political or religious commitments" (p. 2022). As Abd-El-Khalick et. al. say, science is "socially and culturally embedded" (p.418).

## Approaches to Teaching How Science Works

The importance of HSW in English education has increased in last two decades, but it is not yet taught as much as might be desirable, despite its inclusion in the National Curriculum. Taber (2008) writes, "the introduction of explicit requirements for teaching about the nature of science…has not automatically led to widespread and effective teaching [of the nature of science]" (p. 200). This deficiency may be remedied in some cases by the introduction of the '21st Century Science' GSCE programme (generally available since September 2006) (Taber 2008). This course comprises nine modules, each of which addresses both one or two 'science explanations' (content) and one or two 'ideas about science' (How Science Works) (Millar 2006). Thus this course explicitly emphasises HSW.

According to Millar (2006), the initial responses of teachers piloting the new course were positive. After 1 year of the pilot project, 35 out of 40 teachers considered that the course had been successful or very successful in improving the scientific literacy of their students. Twenty-seven out of 40 thought that their students' interest and engagement was better or much better when following the 21st Century Science course.

There are a number of possible approaches to teaching HSW. Hipkins, Barker and Bolstad (2005) identify the possibility of processing secondary data as a means of students gaining experience of how scientists work. They suggest the examination of historical case studies as another option, as well as the inclusion of sociological aspects of the nature of science. Hammrich and Blouch (1998) describe a "cooperative controversy" approach (p. 50) in which students are asked to defend either the view that "science is fact" or the view that "science is myth" in a debate. The students are asked to then reach an agreement as to the true nature of science.

Seker & Welsh (2006) conducted a study in which they investigated three approaches to incorporating History of Science into eighth-grade (English year 9) science lessons. The first approach involved planning lessons taking into consideration the similarities between students' alternative conceptions and ideas held by scientists in the past. The second approach involved discussion sessions concerning the scientific method – this was an explicit approach to teaching HSW. The third approach involved exposing the students to stories about scientists' personal lives without explicit connection to HSW, and thus, like the first approach, was an implicit approach to teaching HSW. Four classes taught by the same teacher were followed over four months. Each class was taught using one of the History of Science approaches, with the fourth class taught using a traditional curriculum. Seker and Welsh studied the effect of these approaches on students' learning, HSW perceptions and interest in science.

They found that students' learning was not affected by the History of Science approaches. There was some effect on students' understanding of HSW, however. All three History of Science approaches were found to be more successful at developing students' understanding of the scientific method than the traditional approach. Students' understanding of inference was most benefited by the second and third historical approaches. However, students' understanding of other aspects of HSW (tentativeness and subjectivity) did not appear to be affected by which class they were in. They also found that student interest in science in general decreased for students in the first two classes. However, they found that "scientists' personal life stories consistently affected student interest positively" (Seker & Welsh 2006 p. 78).

It should be noted that it is not strictly possible in small-scale educational research to compare the subjects of an intervention with students in an identical control group for the simple reason that no two classes or lessons are ever identical. Whilst "control groups" may provide a useful benchmark, we must bear in mind that there are many uncontrollable factors which influence students' learning.

Khishfe (2008) studied the development of seventh-grade (English year 8) students' views of four aspects of HSW in a small-scale study. This study yielded results which "support the claim that an explicit inquiry-oriented approach can improve students' views of [HSW]" (Khishfe 2008 p. 490). It was also found that "the change of students' [HSW] views, from naïve to more informed, appeared to undergo a developmental process. Using an explicit inquiry-oriented approach, students' views of [HSW] continuously and gradually improved." (p. 491)

Abd-El-Khalick et. al. (1998) refer to HSW teaching techniques as either content-embedded or generic. Content-embedded activities teach aspects of HSW using actual scientific content as a context – for example drawing inferences from observations of fossil fragments. In generic activities, students studied the behaviour of a "black box" – i.e. an unknown phenomenon. "Students were then asked to design and construct models that mimic the behavior of the original phenomenon without ever 'seeing' what was inside the 'black-box' " (p. 421). The students were thus learning about the generic process of modelling rather than studying a specific scientific model. Khishfe and Lederman (2006) review a small number of studies which compare the two approaches and conclude that "the existing evidence is inconclusive regarding the effectiveness of existing efforts that utilized integrated [content-embedded] and nonintegrated [generic] approaches on students' learning of [HSW]" (p. 397). Their own research (outlined below) suggested that students' understanding of HSW improved when it was taught explicitly, but the data did not conclusively favour either an integrated or nonintegrated approach.

We may conclude that these studies suggest that explicitly teaching HSW can be effective in changing students' conceptions of HSW. Implicit incorporation of HSW appears to have a more limited positive effect. It appears that student interest in science is not affected positively by explicit teaching of HSW, but students do appreciate learning about scientists' personal lives.

**The Methodologies of Previous Studies**

In this section, I shall review methodologies employed by other researchers investigating the teaching of HSW.

Denscombe (2007) identifies four methods employed in social research: questionnaires, interviews, observation and examination of documents. Questionnaires (and tests) and interviews are methods particularly applicable to probing students' understanding of HSW.

According to Khishfe (2008), in recent years there has been a change in the questionnaire instruments used to probe students' understanding of HSW. Traditionally, instruments such as the Test of Understanding of Science (Klopfer & Cooley 1961 cited in Khishfe 2008) have been used, which assign a numerical score to the adequacy of students' views rather than providing a reliable picture of what views students hold. Consequently, researchers have recently chosen to use questionnaires with open-ended questions, which can be followed up with interviews.

For example, in the study referred to above, Khishfe and Lederman (2006) report on the teaching by the same teacher of two ninth grade (i.e. English year 10) classes where one class was taught using an integrated approach, and the other using a nonintegrated approach. They administered the same open-ended questionnaire before and after the teaching sequences, choosing not to use "forced-choice" questions to allow "respondents to explicate their own views and the assumptions that underlie these views" (p.399). Students in a randomly selected sample (about 25%) were given semistructured individual interviews before the intervention. Another 25% were randomly selected for interview after the intervention. The interviews were used to validate researchers' interpretations of the students' questionnaire responses.

Some researchers have used a mixture of open and closed questions to elicit students' understanding of HSW. For example, Solomon, Duveen, Scot and McCarthy (1992 cited in Khishfe 2008) devised a questionnaire containing multiple choice questions and an essay question.

Multiple choice questions are clearly quicker to analyse and may be the only practical solution if a large sample of students is to be surveyed. Where time permits, however, using open-ended questions clearly has the potential to provide a more authentic picture of what students think.

Another instrument, discussed by Seker & Welsh (2006), which may be used to probe students' understanding of subject matter is the concept map. This is a diagram in which concepts and relationships are shown graphically, which students are asked to create or complete. This may be a more challenging test of students' understanding than a questionnaire, and so has the potential to reveal a very detailed picture of students' conceptions in an area such as HSW.

Whatever research probes are used to assess students' conceptions, they are often applied twice: once before and once after a teaching sequence. However, this does not have to be the case. The probing of students' ideas during an intervention as well as before and after can be done in an effort to yield information on the way in which students' ideas about HSW develop over time (Khishfe 2008). In Khishfe's study, the HSW views of 18 seventh grade students (English year 8) were probed using an open-ended questionnaire and (in six cases) semi-structured individual interviews before, during and after a teaching sequence. During this teaching sequence, students were given three problem-solving tasks related to science content being taught. Following each activity, students were guided to explicitly discuss aspects of HSW in relation to the task they had carried out.

The eliciting of students' views during the course of an intervention obviously has the potential to provide researchers with a more detailed picture of the effect of the intervention on students. However, it is an approach designed to answer research questions about the development of students' views of HSW. It is not as relevant to studies which seek to determine only the overall effect of a particular intervention.

In this study, open-ended questionnaires and interviews were used before and after a teaching sequence, along with other probes. They are described in below.

## Context

The intervention to be described in this report took place during six consecutive sixty-minute physics lessons of a year 10 group at a coeducational 11-16 comprehensive school in England. The lessons fell in February and March 2009. All 17 students in the group had chosen to take three science GCSEs instead of the school's default option of two GCSEs. The class, known as 10YSep, was mixed ability, with a fairly wide range of students present. Shortly after this intervention, the present author and the class' usual physics teacher predicted the grades shown in Figure 1 for the students in the class.

The class were following the OCR Gateway GCSE syllabus, a program of study which does not place the same emphasis on HSW as 21$^{st}$ Century Science does. At the start of this intervention, the class' usual teacher, who had taught them since the previous September, was replaced by the present author, an education student placed at the school for the purposes of Initial Teacher Training specialising in physics.

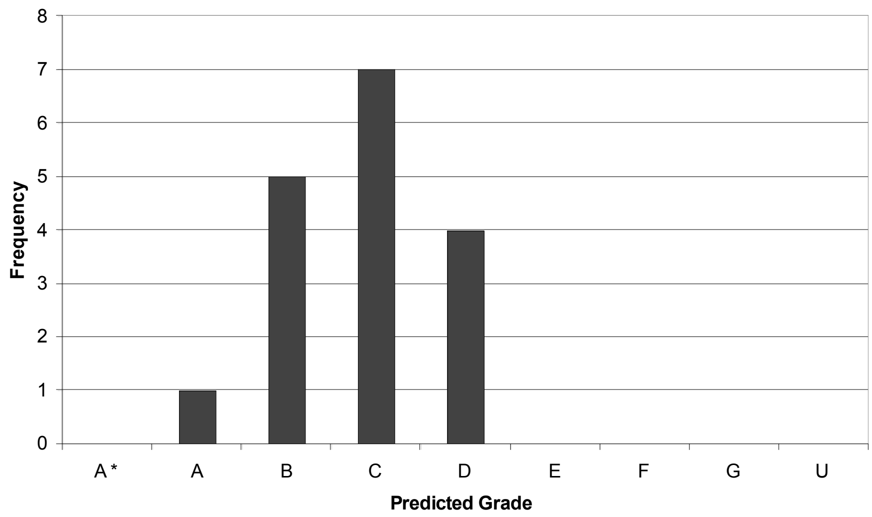



**Figure 1: Predicted GCSE Grades for 10YSep.**

## Research Questions

This study will seek to answer the following questions:

I. Is focussing lessons on *How Science Works* an effective way of teaching *How Science Works* to 10YSep?

II. Is focussing lessons on *How Science Works* an effective way of teaching the *space* topic to 10YSep?

III. How does focussing lessons on *How Science Works* affect the motivation of students in 10YSep?

Thus three potential effects of focussing lessons on HSW will be examined. This research is grounded in the importance of teaching HSW to secondary students; effective teaching of HSW is its main aim. However, focussing lessons on HSW whilst still aiming to teach about space has the potential to affect the students' learning of the space material, so this is also examined.

The introduction of a particular teaching approach may well affect students' motivation, which itself affects their learning. The effect, which could be positive or negative, is worth investigating, because an 'effective' teaching approach which students do not enjoy has limited benefits. If students' motivation to study science can be increased by a focus on HSW, the benefits of this focus may extend beyond an understanding of HSW to greater engagement with science education as a whole. As discussed in Section 3.3, teachers have reported that students seem to respond well to the '21$^{st}$ Century Science' GCSE course (Miller 2006). This study investigates whether or not such positive responses can be reproduced in a different context.

## Methodology

This study uses an action research methodology since it is concerned with investigating the effect of changing the way 10YSep are usually taught, rather than studying in detail a pre-existing situation, which would comprise a case study. I shall describe in detail the methods used in this study below.

I shall first outline the way the HSW and space material was organised into lessons, and then consider the data collection and analysis methodologies employed.

**Teaching**

The main learning objectives chosen for each lesson concerned aspects of HSW. These were based on students' alternative conceptions in this area as described in the literature. The HSW teaching was illustrated using material on space drawn from items P2g and P2h of the OCR Physics B specification (OCR 2005 p. 102-107). Most lessons were organised such that the HSW material formed the main focus of or context for the lesson, i.e. the approach to teaching HSW was "integrated".

The organisation of the HSW and space learning objectives into lessons is shown in Table 1. This table also outlines the activities planned for the lesson, excluding those revising previous lessons' work.

**Data Collection**

The research questions addressed by this study do not concern the process by which students' conceptions are changed, so few data concerning students' learning were collected during the intervention. Rather, the main probes were administered before and after the teaching sequence. They are described below, in approximate chronological order.

Before the sequence of lessons, the students all completed a test/questionnaire containing questions about both HSW and space, as well as questions probing their attitudes to science lessons. These questions are shown in Appendix A1.1. Some of the attitude questions were multiple choice, but all HSW questions were open-ended, which means they had the potential to provide a more accurate picture of students' conceptions, as discussed above.

Three students were then interviewed about their understanding of HSW. The questionnaire responses were used to attempt to select students for interview who would show a variety of levels of understanding.

| Lesson | Learning Objectives | Outline of Activities | |
|---|---|---|---|
| | How Science Works (references as in Section 3.2) | Space (quoted from OCR 2005 p. 102-107) | |
| 1 | Know what sorts of questions are scientific questions.<br>State the main reasons why scientific work is carried out.<br>Understand the difference between science and technology. | Describe that observations of Near Earth objects (NEO) can be used to determine their trajectories.<br>Suggest and discuss possible actions which could be taken to reduce the threat of Near Earth objects. | Sorting and brainstorming exercises to explore HSW learning objectives, using the study of and protection from NEOs as examples. |
| 2 | Know what is meant by scientific laws, models and theories.<br>Understand that science is descriptive rather than prescriptive. | Describe the life history of a star (mediumweight and heavy weight). | Discussion and illustration using game of laws, theories and models. Stellar evolution presented as an example of a theory and studied independently by students. Plenary reinforced the difference between laws, theories and models using stellar examples. |
| 3 | Understand that science is descriptive rather than prescriptive.<br>Understand the distinction between observations and inferences. | Describe that asteroids: are left over from the formation of the solar system; orbit between Mars and Jupiter.<br>Explain why the asteroid belt is between Mars and Jupiter.<br>Describe some of the evidence for past asteroid collisions. | Discussion and work in pairs to explore the HSW learning objectives. Independent study of asteroids, identifying observations and inferences in textbook. |
| 4 | Describe the role of evidence in the verification of scientific theories.<br>Understand why scientists can never be absolutely sure that a theory is correct, and what is meant by scientific proof. | Describe that: all galaxies are moving away from us; distant galaxies are moving away more quickly.<br>Explain how the Big Bang theory accounts for: light from galaxies is shifted to the red end of the spectrum; the further away galaxies are, the greater the red shift. | Discussion of HSW learning objectives, illustrated by Big Bang theory and the evidence for it taught<br>using a video and a balloon. |
| 5 | Describe the role of prediction in the verification of scientific theories. | Describe that comets: have highly elliptical orbits; are made from ice and dust; are objects orbiting the Sun far beyond the planets.<br>Describe that the speed of a comet increases as it approaches a star.<br>Explain why the speed of a comet increases as it approaches a star…. | Independent group work researching Halley's comet<br>and his prediction and producing a poster. |
| 6 | Explain why scientific knowledge may change over time.<br>Describe the role of the scientific community in the verification of scientific theories. | Describe that…microwave radiation is received from all parts of the universe.<br>Explain how the Big Bang theory accounts for…the age and starting point of the universe. | Sharing of research on Big bang theory done for homework. Video on cosmic microwave background radiation. True/false card sort about the role of the scientific community. Guessing the age of the universe. |

**Table 1: The Teaching Sequence.**

The selection of students for interview was also affected by individuals' willingness to participate. Details of the interviewed students are shown in Table 2. The interviews were all fairly short and conducted one-to-one. They were loosely structured around discussion of the students' responses to the questionnaire, enabling a more detailed picture of these students' ideas to be constructed.

At the end of each lesson, all students were asked to complete a short anonymous questionnaire about their opinion of the lesson. This was done to provide data about factors affecting students' motivation. In most lessons, this questionnaire (reproduced in Appendix 2.1) sought to elicit students' opinions on four aspects of the lesson which could have affected their motivation: enjoyment, interest, difficulty and the pace. The use of multiple choice questions allowed the slips to be completed and processed rapidly, although space for additional comments was also given.

| | **Student A** | **Student B** | **Student C** |
|---|---|---|---|
| **Fisher Family Trust 'D' predicted GCSE grade** | C | C | A |
| **Teachers' predicted grade for physics** (assigned after the teaching sequence, taking the results of the end of unit test into account) | C | B | A |
| **Score in pre-teaching HSW test questions** | 36% | 9% | 36% |
| **Score in post-teaching HSW test questions** | 73% | 95% | 27% |
| **Gender** | Male | Female | Male |

**Table 2: Details of the Students Interviewed.**

Data on students' conceptions of HSW were collected from two in-lesson activities. Firstly, marks from a starter quiz in lesson two were collected and recorded. Secondly, after the teaching sequence, the students had two revision lessons covering material from both topics. In one of these lessons, the students were given a circus of HSW and space activities (only two of which introduced new material) which they worked through in any order at their own pace. These tasks were marked and the marks were recorded. After the intervention, all students completed a standard end of unit test for P2 which included some questions on space. Additional questions on space and HSW were appended to the test. These were almost identical to a number of the open-ended questions on the pre-teaching test. In addition, students were given an anonymous questionnaire probing their attitudes towards the teaching sequence. The three students who had been interviewed were then interviewed again. They were first asked about their opinions of the teaching sequence and were then asked a series of questions about HSW which were almost identical to questions they had been asked in their first interview. The data collected are summarised in Table 3 below.

| **Data Type** | **Source** | **Number of Students** | **Research Question being probed** | | | **Materials reproduced in** | **Data shown in** |
|---|---|---|---|---|---|---|---|
| | | | **Effectiveness of HSW Teaching** | **Effectiveness of Space Teaching** | **Effect of Intervention on Motivation** | | |
| Test Marks | Pre-teaching test | 16 | ✓ | ✓ | | Appendix 1 | Table 4 Table 5 Figure 2 Figure 4 Appendix A4.1 |
| | P2 end of unit test | 17 | | ✓ | | | |
| | Questions appended to end of unit test | 17 | ✓ | ✓ | | Appendix 4 | |
| Classwork Marks | Starter quiz in lesson two | 16 | ✓ | | | | Appendix A3.1 |
| | Revision circus after teaching sequence | 16 | ✓ | ✓ | | | Figure 3 |
| Questionnaire Responses | Questionnaire part of pre-teaching test | 16 | | | ✓ | Appendix 1 | Appendix **Error! Reference source not found.** |
| | Questionnaire at the end of each lesson | Up to 17 | ✓ | ✓ | ✓ | Appendix 2 | Appendix 2 |
| | Questionnaire appended to end of unit test | 17 | | | ✓ | Appendix 2 | Figure 5 Figure 6 Appendix 5 |
| Interview Transcripts | Pre-teaching interviews | 3 | ✓ | | | **Error! Reference source not found.** 2 | Table 5 Table 6 |
| | Post-teaching interviews | 3 | ✓ | | ✓ | | |
| Audio Recording | Every lesson | Up to 17 | | | | Not used | |

**Table 3: Inventory of Data Collected.**

## Data Analysis

### Marked Work

The responses to the open-ended pre-teaching HSW questions were coded using a system developed in response to the answers the students gave, and the modal categories were identified.

The responses from the pre-teaching test and the (almost identical) questions appended to the end of unit test were marked according to the same mark scheme and the average mark gained on each question was calculated. The percentage improvements between tests in the average HSW mark and the average space mark were calculated.

The questions from these tests and the end of unit test were divided into three categories: HSW questions; questions on space material taught during this intervention; and questions on material taught before this intervention started. The former two categories were further divided into questions answered before and after the teaching sequence. The scores gained in each category were plotted on cumulative frequency graphs. Thus the spread of marks gained in each category could readily be compared. This was also done for the quiz in lesson two, and in the revision circus tasks (see Appendix 3).

Cumulative frequency graphs were chosen because they provide a visualisation of the spread of marks across the class, which gives more information than a mean and standard deviation alone would. Non-cumulative histograms were not used in order to avoid misleading effects due to the binning of data.

It was necessary to account for the fact that some students took a foundation tier end of unit test while others took a higher tier equivalent. In order to obtain comparable data, the marks from the foundation tier paper were reduced to approximately equivalent higher tier paper marks before further analysis. The conversion function was determined by comparing the grade boundaries supplied with each mark scheme and using linear interpolation.

**Questionnaires**

Students' responses to the pre- and post-teaching questionnaires were analysed by calculating the frequency of different responses to each question and viewing these as pie charts, which are shown in Appendices  and   The modal responses to the pre-teaching questionnaire were identified in order to build up a picture of the common attitudes in the class.

There were a variety of opinions in the class on most questions, so further analysis was carried out to ascertain the extent to which the class fell into distinct groups with different but internally consistent views. To do this, each response to this questionnaire was coded as positive, negative, or neutral about HSW and the teaching sequence. Students who returned four or more responses (out of the six questions) which fell into the same category were deemed to hold that opinion overall. Other students were deemed to be of mixed opinion.

The questionnaires filled in at the end of each lesson were used to calculate "mean opinions" of the class about each lesson (see Appendix 2). These were plotted on bar charts to compare lessons to each other. In addition, all questionnaires received during the intervention were analysed together and the overall frequency of each response was calculated and plotted on pie charts.

**Interviews**

The six interviews were transcribed, and students' responses to the same questions before and after the teaching sequence were compared. The findings of the interviews were summarised by collating each student's opinions about the teaching sequence, and comparing their responses to HSW questions before and after the teaching sequence. This comparison included triangulation with their HSW test question responses. The summaries are shown in Table 5 and Table 6 .

**Triangulation**

Triangulation is the use of multiple sources of data to examine the same research question. The data collected in this study allow both methodological triangulation (comparison of data from interviews with HSW tests and opinion questionnaires) and time triangulation (comparison of data from questionnaires during and after the intervention) (Denscombe 2007). Denscombe (2007) identifies two purposes for triangulation: “improved accuracy” or gaining a “fuller picture” (p.138). In this study, triangulation was used for both purposes.

### Validity and Reliability of the Data Collected

Similarities with earlier studies suggest that the methods used in this study are valid ways of probing the research questions under consideration. However, there are a number of constraints and limitations affecting this research.

No “control” group is used for comparison, since this author did not teach another class of the same type at the time. This makes it harder to demonstrate the reliability of the data collected and conclusions drawn. Although a true control is not possible in educational research, comparison of different classes can be instructive.

Constraints on time meant that more detailed data collection (for example, the interviewing of more students) was not feasible. The selection of certain data for collection inevitably compromises the reliability of the information gained (Wilson 2009). For example, there is no guarantee that the sample interviewed is representative of the class, especially as it was partially governed by which students were willing to take part.

## Findings

### The Teaching of How Science Works (Research Question I)

The modal responses to the pre-teaching HSW test questions are shown in Table 4 below. These data reveal that a large number of responses were partially correct or expressing ignorance. Thus we may draw the broad conclusion that before this intervention, there were few widely held alternative conceptions concerning HSW, but significant levels of ignorance in this area. This conclusion is supported by triangulation with the following comment made in a post-teaching interview:

Interviewer: So, over the last few weeks we’ve been focussing our science lessons on How Science Works. …I wondered, do you think, was it a helpful way to learn about How Science Works?

Student B: Yeah, because at the start of the year, hardly any of us knew anything to do with science [presumably HSW?].

I: OK, so are you…do you think it's an important thing to know about?

B: Yeah.

| Question | | Modal Response Category | Number of Responses in this Category |
|---|---|---|---|
| 6 | What is the purpose of a scientist's work? | Discovery/understanding (a partially correct response) | 13 (76%) |
| 7 | How are new scientific theories discovered? (A theory is an explanation of why certain things happen e.g. Isaac Newton's theory of gravity explains why things fall towards the Earth.) | Experimentation etc. (partially correct) | 9 (53%) |
| 8 | Is it possible to prove that a scientific theory (e.g. Newton's theory of gravity) is definitely correct? If it is possible, how would this be done? If it isn't possible, why not? | No (correct) | 7 (41%) (6 students said yes) |
| 9 | Sometimes scientists disagree with each other about whether a scientific theory is correct. Why do you think this is? | Different opinions (a vague response) | 7 (41%) |
| 10 | When a scientist proposes a new theory, who decides whether the new theory should be accepted by all other scientists? | Don't know | 8 (47%) |
| 11 | Once a theory has been accepted by scientists, can it ever get changed or replaced by new a one? If this can happen, when would it happen? If it can't happen, why not? | Don't know/ambiguous | 9 (53%) |
| 12 | Are there any scientific ideas that you know about that you think might one day be replaced by better theories? | A clearly sensible idea given | 5 (29%) |
| | | Don't know | 5 (29%) |

**Table 4 Modal Responses to the Pre-Teaching How Science Works Test Questions.**

Figure 2 below shows a comparison of the marks gained on the same HSW test questions before and after the teaching sequence. It shows that noticeably fewer students gained low marks on these questions after the teaching sequence. In other words, the students' ability to answer these questions appears to have generally increased as a result of the teaching sequence. These data are presented in a different format in Appendix 4.1. The mean score on HSW questions before the intervention was 30% (standard deviation 12%), which rose to 58% (standard deviation 23%) after the intervention – this represents an improvement by 94% of the pre-teaching mean score. (In this paper, standard deviations (s.d.) are quoted as percentages of the maximum possible score, not percentages of the mean score.)

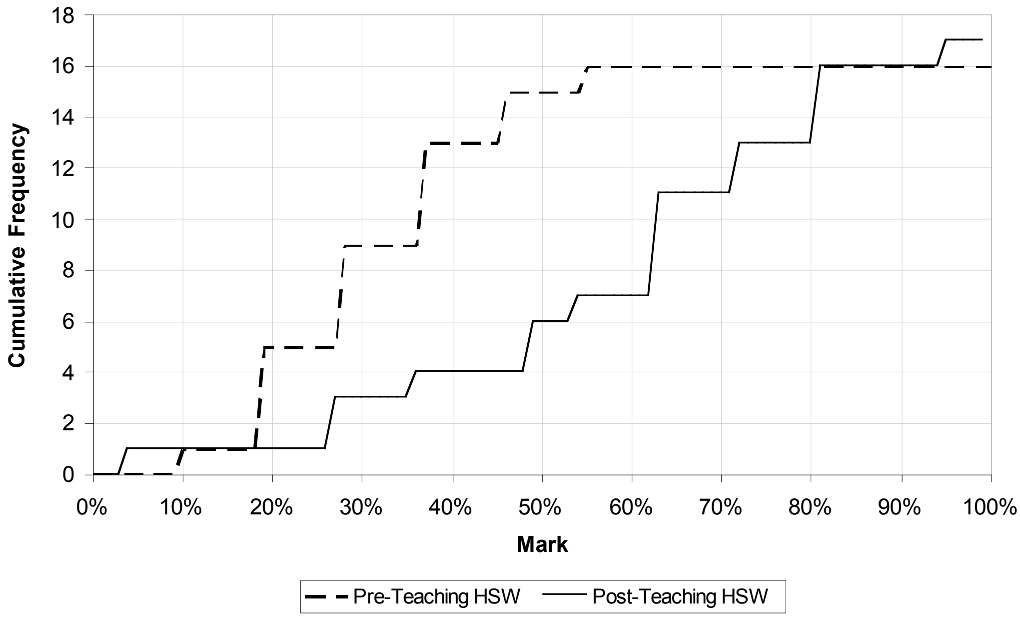



**Figure 2: Marks gained in How Science Works Test Questions before and after the Teaching Sequence.**

It should be noted, however, that even after the teaching sequence there was a large spread in the marks gained: not all students appear to have learned the material thoroughly. However, in such a mixed-ability class, it is to be expected that a range of attainment levels are in evidence. So we may conclude that the lessons were successful in improving students' understanding of certain aspects of HSW. Having said this, the test questions used were significantly biased towards recall questions, and so do not provide a full indication of the depth of understanding achieved by students.

The marks gained by students in the starter quiz in lesson two show a similarly large spread of marks (mean 47%; s.d. 21%), although more students gained low marks and fewer students gained high marks than in the test after the teaching sequence. These data are shown in Appendix 3.1

As shown in Figure 3 below, nearly 40% of the HSW tasks marked in the revision circus scored marks of over 90% (giving a mean score of 68% and s.d. 29%). This may reflect the fact that one of the tasks was a relatively straightforward crossword, and that students had access to their class notes when doing the tasks. Nevertheless, these data indicate that students were often able to use the HSW concepts correctly.

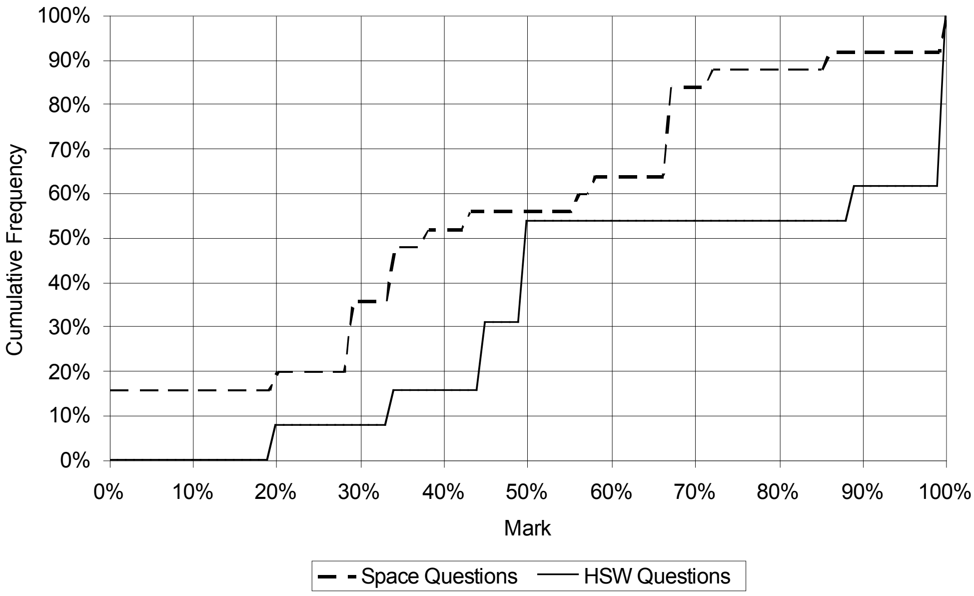



**Figure 3 Marks gained in Revision Circus Tasks**

Changes in the HSW understanding of the three interviewed students were studied in more detail. Table 5 below summarises the extent to which their ideas were changed by the teaching sequence, as evidenced by their comments in interviews and responses to pre- and post-teaching HSW test questions. Data in the first two rows is evidence for positive changes due to the intervention. The third row is neutral, and the last three rows indicate possible failings of the intervention. Therefore the fact that there are many more statements in the first two rows than in the last three is evidence that this intervention had a positive impact on students' understanding of HSW. The table shows few cases of alternative conceptions being replaced by the intervention (the first row). This confirms the conclusions drawn above: before the intervention, students did not hold large numbers of alternative conceptions which could be corrected by the teaching sequence. However, the intervention was successful at introducing students to HSW ideas they were initially unfamiliar with.

| | **Student A** | **Student B** | **Student C** |
|---|---|---|---|
| **Incorrect ideas held before the teaching sequence which were not in evidence afterwards.** | There are some theories [laws?] it is possible to be completely sure about (I) (T). | It is possible to prove that a theory is definitely correct (T). | The general public decide whether a new theory should be accepted (T). |
| **Correct ideas held after the teaching sequence which were not in evidence beforehand.** | Explicit reference to evidence (I).<br>Theories should be reviewed by scientists (T) working in the relevant field (I).<br>Theories known to be wrong can still be useful (I).<br>New scientific theories are discovered from observations and inferences (T). | A clearer idea that scientists work to develop explanations for natural phenomena (I) (T).<br>A slightly clearer concept of the role of evidence in the verification of theories (I) (T).<br>The tentative nature of scientific evidence (I).<br>Currently accepted theories could be changed in the future if more evidence were produced (I) (T). | Scientists work to develop good theories (I) (T).<br>We can never be completely sure that a theory is correct (I) (T).<br>Scientists publish theories in journals (I).<br>Evidence is “a piece of information that proves you’re correct” (I).<br>Experiments are the testing of a theory (I). |
| **Correct ideas held before the teaching sequence which were still present afterwards.** | Theories should be reviewed by other scientists (I).<br>Scientific ideas can change (I).<br>A theory can be replaced if a new one with more evidence (T). | Scientists may be motivated both by interest and the possible applications of their work (I).<br>When multiple theories are proposed, none of them is necessarily right (I). | Good theories can be identified by experimentation (I).<br>There are a variety of areas that scientists work in (I).<br>A theory can be replaced (T). |
| **Incorrect ideas held before the teaching sequence which were still present afterwards.** | [None identified.] | [None identified.] | [None identified.] |
| **Other incorrect ideas held after the teaching sequence.** | [None identified.] | [None identified.] | Scientists vote on which theory to accept (I) (T). |
| **Correct ideas held before the teaching sequence which were not in evidence afterwards.** | Scientists’ opinions may be biased by personal commitments (T). | [None identified.] | Scientists’ opinions may be biased by personal commitments (T). |

**Table 5 Summary of Findings from Interviews and Pre- and Post- Teaching Test Responses about three Students’ Understanding of How Science Works.**

There is good agreement in Table 5 between the data from the interviews and the data from the tests. Of the 12 non-empty boxes in the table, eight contain evidence from both instruments. Twenty-five percent of the statements in the table are evidenced by both instruments. This increases our confidence in the reliability of the data from each instrument.

**The Teaching of the Space Material (Research Question II)**

In the post-teaching questionnaire, the students were asked whether focussing lessons on HSW had made it harder to learn the space material. Eight out of 17 students said no (see Figure A5.2 in Appendix 5 for more statistics), and a pattern emerged in some of their written comments:

- "no they linked"
- "It made it look at the space material in a different way."
- "No, it made it easier for me to understand the Big Bang theory."
- "no it made it easier"
- [written in response to another question] "I found it a help to understand the solar system work so it was helpful at once"

However, a number of students did not share this view: seven said that, to some extent, focussing on How Science Works had made it harder to learn the space material.

Figure 4 shows the marks gained by students in space test questions before and after the teaching sequence. Some, but not all, of the post-teaching questions were identical to questions set before the teaching sequence. The graph shows very little difference in the spread of marks before and after the teaching sequence, and in both cases, a significant proportion of students obtained poor marks. The mean score on space questions before the intervention was 31% (s.d. 21%), which rose to only 33% (s.d. 12%) after the intervention. This represents an improvement of 4% of the pre-teaching mean score.

Figure 4 also shows the marks gained on other questions on the end of unit test – these questions were on material taught by another teacher before the teaching sequence started. Students gained higher marks on these questions than on those taught during the intervention.

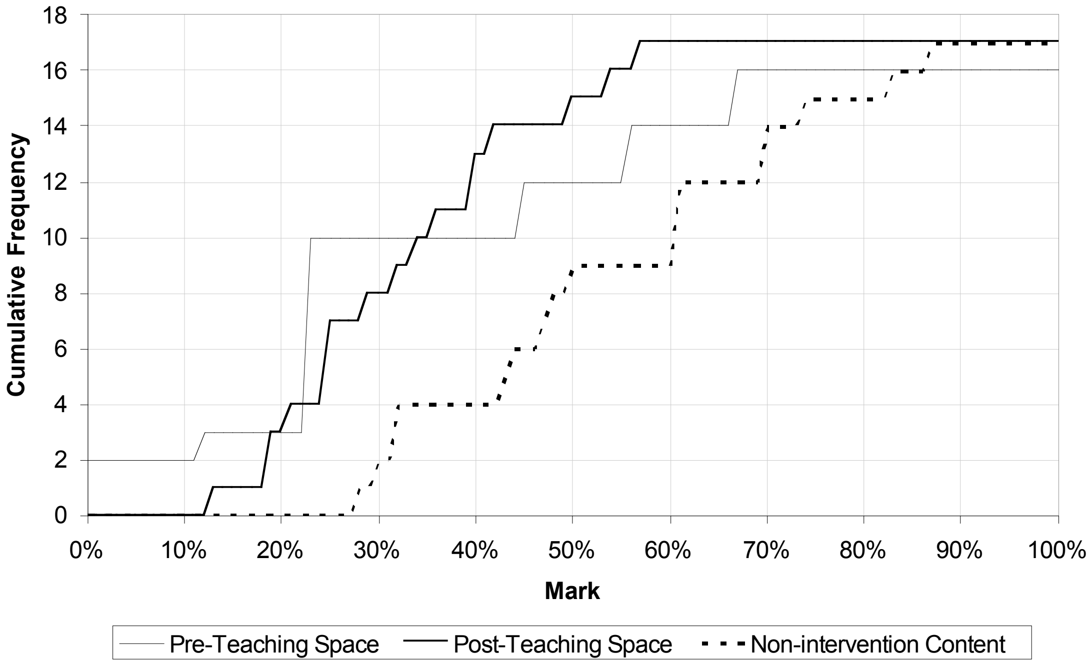



**Figure 4: Marks gained in Space Test Questions before and after the Teaching Sequence.**

The marks gained by students on space tasks during the revision circus are shown in Figure 3 above. These marks are slightly better than those gained in the intervention space questions in the end of unit test, which is not surprising, given that the revision circus tasks were completed by groups of students with access to their class notes.

A slightly inconsistent picture emerges from these data. Students had varying opinions on the effect of the HSW focus on their learning about space, with some students claiming the integrated approach had been beneficial for their learning about space. However, the numerical data suggest that students' ability to answer questions on the space material had not been improved as a result of the teaching sequence.

The post-teaching test questions on the space material included questions in the standard end of unit test as well as questions devised by the present author. Marks gained in these two categories of questions were slightly different: in the questions on this teaching sequence in the end of unit test, students gained a mean mark of 26% (s.d. 15%) (corrected to higher tier equivalent); in the additional space questions, the mean was 38% (s.d. 16%).

**Students' Motivation (Research Question III)**

Before the teaching sequence, the students' attitudes towards physics were broadly positive. The modal responses to the pre-teaching questionnaire were as follows (the data are shown in more detail in Appendix 1):

1. Physics lessons are usually enjoyable.

2. Physics is usually interesting.

3. I work the same [neither harder nor less hard] in physics as in other subjects.

4. More experiments etc. would make me want to work harder in physics.

5. I chose to do triple science because of enjoyment/interest.

In post-teaching interviews, students spoke generally positively about the teaching sequence (perhaps inevitably as they were face to face with the teacher). Their opinions are summarised in Table 6 below. The students' comments about having HSW material concentrated into one sequence of lessons are interesting. Taken together, they suggest that the students felt that learning the material all at once helped their understanding of HSW, but the variety provided by spreading the material out through the curriculum would also be desirable. One student commented that the class would have understood both HSW and space better if the two had been taught separately.

During the intervention, the "mean opinions" expressed on the feedback slips rarely deviated from neutral (see Appendix 2). The most significant deviation from this was in lesson five, in which the mean response indicated that students thought the lesson was "quite enjoyable" and the topic was "quite interesting". This lesson was possibly the least focussed on HSW of the six lessons. However, the students' positive response is likely to be due to the fact that they were given independent group work to do in this lesson, which was not the case to the same extent in other lessons. It should be noted that the feedback slips do not give information solely about the HSW content, or even the teaching approach as a whole. The students' opinions about the lessons would have been affected by a large number of factors, including many factors beyond the control of the teacher. The generally neutral mean responses mask significant polarisation in the actual responses submitted. Thirty-eight percent of the feedback slips collected during the six lessons claimed the lesson was "very enjoyable" or "quite enjoyable", while 28% claimed it was "(Really) not enjoyable". Forty-nine percent of the slips ranked the lesson's topic as "very interesting" or "quite interesting", while 23% said it was "(Very) uninteresting" (see Appendix 2).

| **Question** (not word-for-word) | **Student A** | **Student B** | **Student C** |
|---|---|---|---|
| **Was learning about HSW interesting?** | Yes, about as interesting as scientific content. | Yes, as interesting as scientific content. | Made science slightly more interesting. |
| **Is learning about HSW important?** | Yes, as important as scientific content. | Yes, as important as scientific content. | Yes, as important as scientific content. |
| **Has your opinion of the importance of learning about HSW changed having had the teaching sequence?** | Yes. | No. | |
| **Was it good to learn about HSW in one chunk?** | It would be better to learn it throughout the year, every year, especially in year seven. | It helped students remember the material, but she would have preferred the variety of spreading it out through the year. | It would have been slightly more confusing to have it spread throughout the year. |
| **Was it confusing to learn about HSW and space at the same time?** | No. | Yes, the class would have understood both better if they'd been taught separately. | No. |
| **Has focussing lessons on HSW affected your motivation to do science?** | | No. | It made him slightly more motivated to do science. |

**Table 6: Summary of Findings from Interviews about Students' Opinions of the Teaching Sequence.**

Students had the opportunity to add written comments to their feedback slips. Several slips were returned during the intervention with comments such as “The topic is interesting but the way it is taught could be much better and funner [sic]”. Whilst it is possible that the majority of these comments could be from the same student, they nevertheless highlight a significant issue: the lessons were taught by a student on initial teacher training, whose skill and experience at delivering engaging lessons were likely to be less than the class’ usual teacher’s. This may have coloured the students’ opinions on the lessons.

The responses to the post-teaching questionnaire were also polarised, with no consistent attitudes evident across the class. A number of students were consistently either positive or negative about HSW and the teaching sequence, however. “Consistent” is here taken to mean showing similar attitudes in four or more of the six questions. The results of coding each student as overall positive, negative, neutral or mixed are shown in Figure 5.

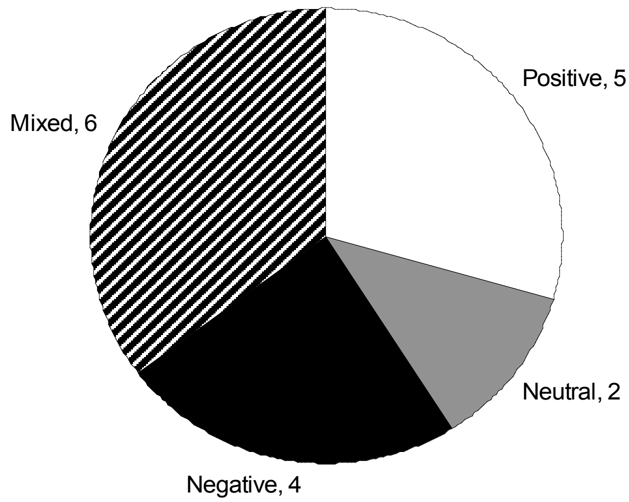



**Figure 5: Overall Opinions of How Science Works and the Teaching Sequence.**

Some students appreciated the opportunity to understand more fully the way science works, as illustrated by this exchange in a post-teaching interview:

| | |
|---|---|
| Interviewer: | Do you think the way we’ve sort of focussed on How Science Works, was that a helpful way to learn about the |

| | |
|---|---|
| | way science works…? |
| Student A: | It's interesting; more interesting than just being told what, well pretty much just being told what to do and how it works; at least you know like the difference, 'cause most people do science and don't even know what it means…they just do it… |
| I: | So, do you think it's important to learn about How Science Works in Schools? |
| A: | Yeah, I think so. |
| I: | Do you think it's more important than the normal sort of science content, the normal stuff we do, or less important or the same? |
| A: | I think it's about the same, but…'cause we need to learn the content as well, course…yeah, I think it's pretty important…what it's about and how it works. |
| I: | Did you think that a few weeks ago; did you think it was important then or is it only having done…? |
| A: | Yeah, I think it's after done it, I didn't really take notice of it before. |

Students were also asked whether the lessons focussed on HSW had made them more or less motivated to learn science. Eight out of 17 students claimed that they were more motivated (see Figure 6 above). Two students were posed this question in interviews: one said no, and the other expressed only a slight increase in his motivation.

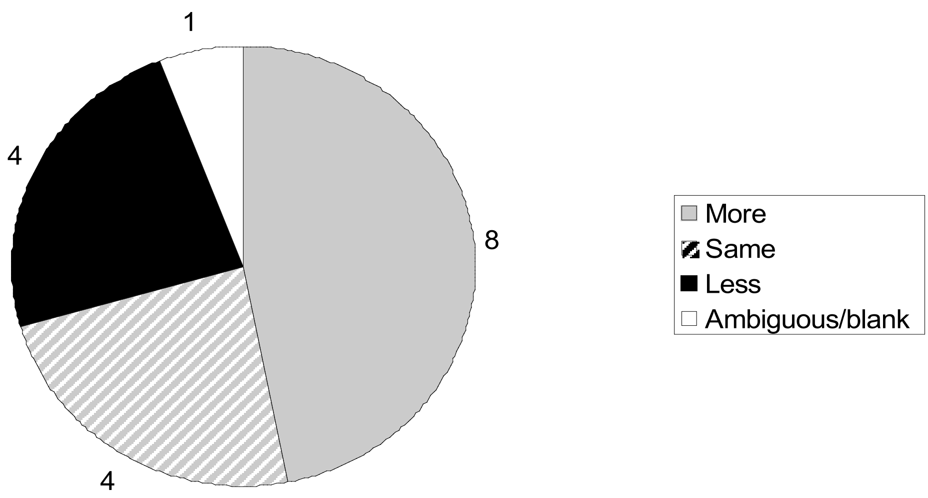



**Figure 6: Responses to Post-Teaching Questionnaire Q6. "Do you think having lessons focussed on How Science Works has made you more or less motivated to learn science?"**

In summary, the opinions of the class about the teaching sequence were mixed: students showed a variety of responses in both the lesson feedback slips and the post-teaching questionnaire.

# Discussion

## Summary of Findings

There are inevitably many factors which affect a class' experience of a sequence of lessons, and their performance in a test. We must be wary, therefore, of drawing strong conclusions about the effects of this intervention. As Denscombe says,

> "Action research, therefore, is vulnerable to the criticism that the findings relate to one instance and should not be generalized beyond this specific 'case'." (2007 p. 130) However, the following reflections may be justified and instructive.

## The Teaching of How Science Works (Research Question I)

The results of this study indicate that teaching HSW in a concentrated series of lessons was a successful way to teach students about HSW. Students gained a wide range of marks on a post-teaching test of HSW knowledge, but these marks were in general significantly better than those gained before the intervention. More detailed examination of three students' HSW conceptions revealed a similar picture of increase in knowledge. Before the intervention, the class was fairly ignorant about HSW, but widespread alternative conceptions were not present. Triangulation between interviews and tests revealed a good degree of consistency, and some students' comments confirmed that they too felt that the approach had been successful in this regard.

### The Teaching of the Space Material (Research Question II)

The teaching sequence appeared to be largely unsuccessful in teaching students about space. Although some students claimed to find learning HSW and space together helpful, test marks did not suggest that much material had been learned. Students were more successful in answering questions about content taught before the intervention started. The value of linking HSW teaching to actual examples of theories from the students' syllabus is evident from the students' responses. However, there appears to be a danger that a focus on How Science Works can jeopardise the students' learning of other material taught simultaneously with it.

### Students' Motivation (Research Question III)

The class held a wide variety of opinions about the teaching sequence. Some wrote positively about the HSW focus and almost half claimed that it had increased their motivation to learn science. An emphasis on How Science Works is not only an agenda of certain academics, its value is appreciated by some students as well: "I think that it was helpful and will be useful in later life, a very good skill to have" (post-teaching questionnaire response). However, such opinions were not held universally; perhaps as a result of the wide variety of students within the class.

## The Significance of these Findings

### The Teaching of How Science Works (Research Question I)

As other studies have done (Khishfe and Lederman 2006, Khishfe 2008), this study provides evidence that explicit teaching of HSW can be effective in increasing students' knowledge about HSW. This suggests that if teachers are to follow the National Curriculum guidance (Taber 2008) that aspects of HSW should be taught to students, explicit teaching of HSW concepts, as done in this teaching sequence, is an approach worth considering. It should be noted, however, that the HSW test questions used in this study probed students' recall more than their understanding.

**The Teaching of the Space Material (Research Question II)**

The space material in the teaching sequence was intended to illustrate the HSW concepts being taught and so enhance the learning of HSW. An unforeseen outcome of this study is that some students found that the reverse was true: the HSW material helped their understanding of the space material. However, it has been shown that it is possible for students to learn HSW at the expense of other content, and teachers should be wary of this danger if an integrated approach is taken. The teaching sequence used in this intervention was intended to be effective in teaching space material as well as HSW, but nevertheless it was not successful in this.

There is no reason to suppose that this deficiency is inevitable. Indeed, there are many possible explanations for the low post-teaching space marks. It may be that the teaching was inadequate, or it may be that students found the questions used in the tests particularly challenging. Alternatively, students' revision may have focussed on material learned earlier in the unit because they thought they had forgotten more of it, or because they didn't realise that the space material taught during the HSW lessons was examinable, though they had been told that it was at the start of the intervention.

If it is desired to teach HSW explicitly without risking the neglect of other important content taught at the same time, a nonintegrated approach may be considered such as that investigated by Abd-El-Khalick et. al. (1998) and Khishfe and Lederman (2006). It will often be necessary or desirable to teach HSW with reference to actual scientific theories. However, the theories used could be drawn from material outside the students' syllabus, or from science content already taught. In this way, HSW may be taught explicitly without risking poor learning of other material at the same time.

As discussed above, Khishfe and Lederman's (2006) conclusions were in favour of explicit teaching of HSW, but inconclusive regarding the relative merits of integrated and nonintegrated approaches. This suggests that it is possible to successfully use an integrated approach. It also implies that it is not directly detrimental to choose a non-integrated approach, although doing so may adversely affect the time available for other studies.

**Students' Motivation (Research Question III)**

Whilst the poor space marks are not inevitable, the fact that students' opinions about the teaching sequence varied probably is inevitable. No class is homogeneous, and different teaching strategies will appeal to different students. The fact that some students were fairly consistently positive in their opinions of this strategy suggests that it has potential to increase the motivation of some students – perhaps those interested in taking their science education beyond learning of content. It may be that if the actual teaching techniques employed were refined, this strategy could be made to appeal to a greater range of students.

**Suggestions for Further Research**

This study investigated the effects of a particular approach only in a very specific situation. Further research could be done in order to determine its effectiveness for teaching other science content or other HSW content. Equally, further research would be needed to discover how effective it was for other groups of students, especially groups in which alternative conceptions of HSW were widely held.

There are a number of ways in which the design of this research could be developed. It would be beneficial to probe students' understanding of HSW more deeply, perhaps using instruments such as concept maps (Seker & Welsh 2006) or problem-solving tasks (Khishfe 2008) in order to discover whether this teaching sequence is effective in giving students a thorough understanding of HSW issues.

It is not clear from this study why students' learning of the space material appeared to be poor. It would therefore be instructive to conduct research with the intention of discovering this – either by probing students' understanding of the scientific content more thoroughly, or by changing aspects of the teaching sequence to identify ways in which the content may be taught more effectively.

More information on the effect of a HSW focus on students' motivation may be obtained by the use of a more detailed probe, for example Seker & Welsh's "Interest Survey" (2006 p. 68).

Teaching HSW in a concentrated sequence of lessons is not the only option. In a post-teaching interview, Student A said, "I think if you like every year learned a bit [of HSW] it would be good…start in year seven and…cover just How Science Works, then we could learn the content stuff…I dunno if you did it, I think bit by bit in the year, every year would be better." It would be valuable to conduct further research to compare the effects of teaching HSW in a concentrated sequence of lessons with teaching HSW gradually through the year, or at the start of students' secondary school career.

## Conclusion

This approach to teaching How Science Works is not the only viable one, and carries vulnerabilities as well as advantages. However, it is an option that is worthy of consideration by teachers who want to give their classes a clear grasp of the nature of the subject they are studying. More research is required to determine in detail the advantages and disadvantages of this approach. Nevertheless, it is important for students to learn How Science Works, and the explicit approach taken in this study can help to ensure that they grasp the concepts involved.

## References

Abd-El-Khalick, F., Bell, R. L., and Lederman, N. G. (1998) The nature of science and instructional practice: Making the unnatural natural, Science Education, 82 (4), 417-736. http://www3.interscience.wiley.com/cgi-bin/fulltext/32150/PDFSTART (Accessed 31/01/09)

Albe, V. (2008) Students' positions and considerations of scientific evidence about a controversial socioscientific issue, Science & Education, 17, 805-827. http://www.springerlink.com/content/f84576333018g509/fulltext.pdf (Accessed 25/05/09)

Denscombe, M. (2007) The good research guide for small-scale social research projects, 3rd edition (Maidenhead, Open University Press)

Driver, R., Leach, J., Millar, R. and Scott, P. (1996) Young people's images of science (Ballmoor, Buckingham, Open University Press)

Hammrich, P. L. and Blouch, K. K. (1998) A cooperative controversy lesson designed to reveal students' conceptions of the "nature of science", The American Biology Teacher, 60(1), 50-51. http://www.jstor.org/stable/4450412 (Accessed 25/05/09)

Harcourt Education (2006a) Gateway Science Suite B: GCSE in Science: End of Module Tests: P2 Module Test: Foundation Tier

Harcourt Education (2006b) Gateway Science Suite B: GCSE in Science: End of Module Tests: P2 Module Test: Foundation Tier: Mark Scheme

Harcourt Education (2006c) Gateway Science Suite B: GCSE in Science: End of Module Tests: P2 Module Test: Higher Tier

Harcourt Education (2006d) Gateway Science Suite B: GCSE in Science: End of Module Tests: P2 Module Test: Higher Tier: Mark Scheme

Harrison, A. G., and Treagust, D. F. (2000) A typology of school science models, International Journal of Science Education, 22 (9), 1011-1026. http://pdfserve.informaworld.com/428074_731220461_713864402.pdf (Accessed 31/01/09)

Hipkins, R., Barker, M. and Bolstad, R. (2005) Teaching the 'nature of science': modest adaptations or radical reconceptions?, International Journal of Science Education, 27(2), 243-254. http://pdfserve.informaworld.com/769803_731220461_714033279.pdf (Accessed 02/05/09)

Khishfe, R. (2008) The development of seventh graders' views of nature of science, Journal of Research in Science Teaching, 45(4), 470–496. http://www3.interscience.wiley.com/cgi-bin/fulltext/117864104/PDFSTART (Accessed 25/05/09)

Khishfe, R. and Lederman, N. (2006) Teaching nature of science within a controversial topic: integrated versus nonintegrated, Journal of Research in Science Teaching, 43(4), 395-418. http://www3.interscience.wiley.com/cgi-bin/fulltext/112470738/PDFSTART (Accessed 25/05/09)

Millar, R. (2006) Twenty First Century Science: insights from the design and implementation of a scientific literacy approach in school science, International Journal of Science Education, 28 (13), 1499-1521. http://pdfserve.informaworld.com/42675_731220461_758856936.pdf (Accessed 02/02/09)

Millar, R. and Osborne, J. (eds.) (1998) Beyond 2000: Science education for the future (London, School of Education, King's College London). http://www.york.ac.uk/depts/educ/research/Beyond%202000.pdf (Accessed 02/02/09)

Oxford Cambridge and RSA Examinations (OCR) (2005) GCSE Science B Gateway Science Suite Specification (Cambridge)

Seker, H. and Welsh, L. C. (2006) The use of history of mechanics in teaching motion and force units, Science & Education, 15, 55-89. http://www.springerlink.com/content/atk22485065h0815/fulltext.pdf (Accessed 25/05/09)

Somekh, B. (1995) The contribution of action research to development in social endeavours: a position paper on action research methodology, British Educational Research Journal, 21(3), 339-355. http://www.jstor.org/stable/1501651 (Accessed 25/05/09)

Taber, K. S. (2008) Towards a curricular model of the nature of science, Science & Education, 17, 179-218.

# Appendices

## A1 Pre-teaching Questionnaire

Below are the questions from the pre-teaching questionnaire, and the responses to the first five questions.

Your Physics Lessons

For these questions, write down the letter of the statement that is most true for you:

1.

A. Physics lessons are always enjoyable.

B. Physics lessons are usually enjoyable.

C. Physics lessons are sometimes enjoyable.

D. Physics lessons are rarely enjoyable.

E. Physics lessons are never enjoyable.

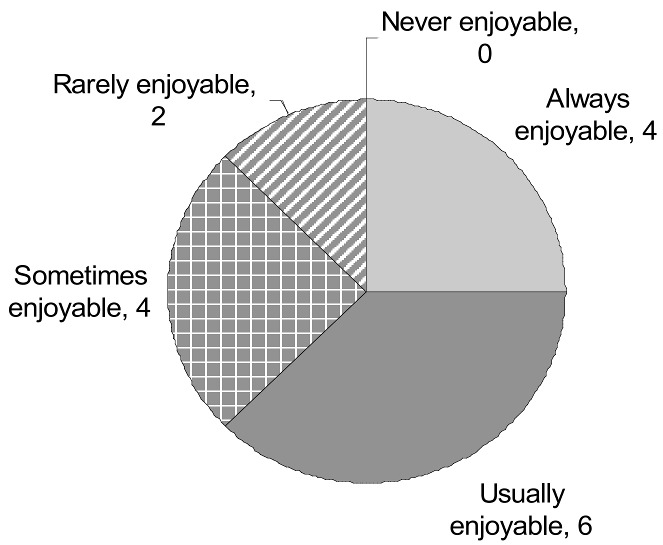



**Figure A1.1: Responses to Pre-Teaching Questionnaire Q1.**

2.

A. Physics is always interesting.

B. Physics is often interesting.

C. Physics is sometimes interesting.

D. Physics is rarely interesting.

E. Physics is never interesting.

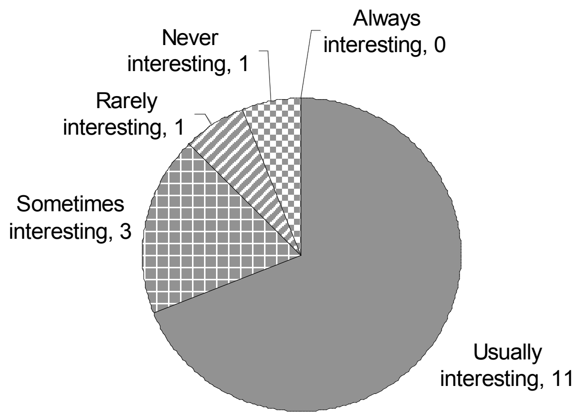



**Figure A1.2 Responses to Pre-Teaching Questionnaire Q2.**

3.

A. I work harder and pay attention more in physics than in other subjects.
B. I work harder and pay attention more in other subjects than in physics.
C. I work the same in physics as in other subjects

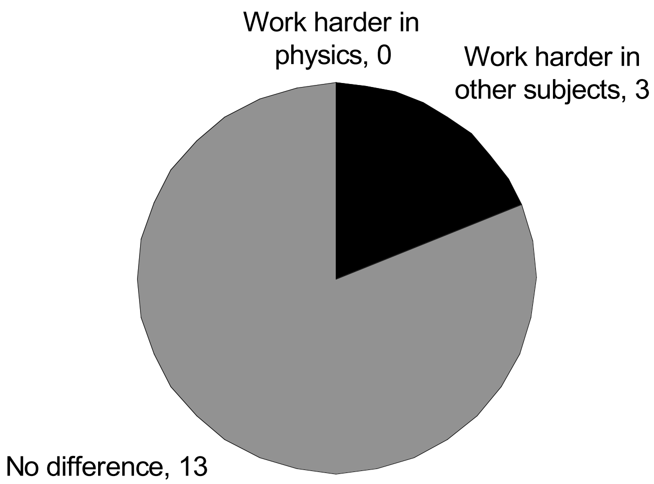



**Figure A1.3 : Responses to Pre-Teaching Questionnaire Q3.**

4. What would make you want to work harder in physics?

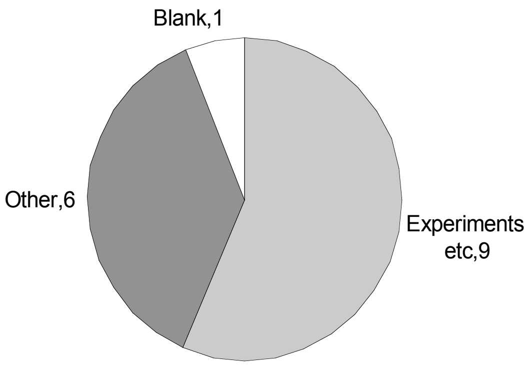



**Figure A1.4 Responses to Pre-Teaching Questionnaire Q4.**

5. Why did you choose to do triple science?

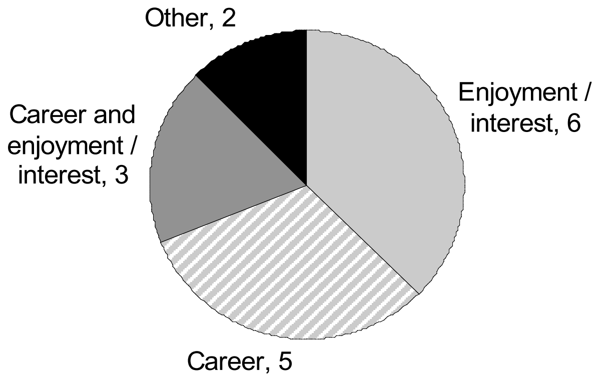



**Figure A1.5 : Responses to Pre-Teaching Questionnaire Q5.**

## How Science Works

6. What is the purpose of a scientist's work?

7.How are new scientific theories discovered? (A theory is an explanation of why certain things happen e.g. Isaac Newton's theory of gravity explains why things fall towards the Earth.)

8.Is it possible to prove that a scientific theory (e.g. Newton's theory of gravity) is definitely correct? If it is possible, how would this be done? If it isn't possible, why not?

9. Sometimes scientists disagree with each other about whether a scientific theory is correct. Why do you think this is?

10. When a scientist proposes a new theory, who decides whether the new theory should be accepted by all other scientists?

11. Once a theory has been accepted by scientists, can it ever get changed or replaced by new a one? If this can happen, when would it happen? If it can't happen, why not?

12. Are there any scientific ideas that you know about that you think might one day be replaced by better theories?

## Space and the Universe

13. Why does the Earth go round the Sun instead of moving in a straight line?

14. What is the difference between a planet and a comet?

15. What is a black hole?

16. What is an asteroid?

17. Do stars ever stop shining? Why/why not?

18. Is the universe getting bigger, getting smaller or does it stay the same size? How do we know?

19. Scientists think that the universe started in the "big bang". What happened in the big bang?

## Appendix 2 . End of Lesson Questionnaire

### Questions

The feedback slip completed by students at the end of each intervention lesson is shown in Figure A2.1. The "pace" question was not present for the first lesson.

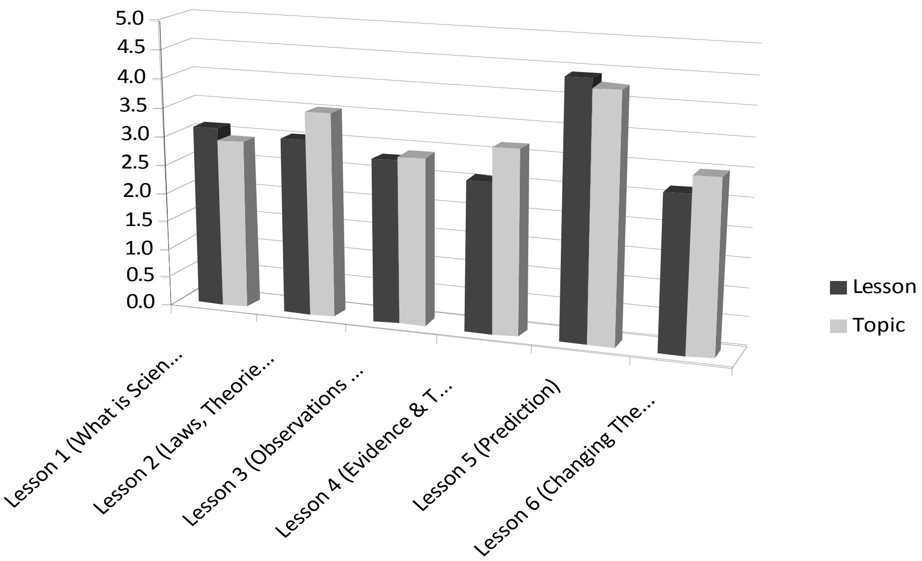
| | |
|---|---|
| Today's lesson was<br>☐ Very enjoyable<br>☐ Quite enjoyable<br>☐ OK<br>☐ Not enjoyable<br>☐ Really not enjoyable | Today's topic was<br>☐ Very interesting<br>☐ Quite interesting<br>☐ OK<br>☐ Uninteresting<br>☐ Very uninteresting |
| Today's work was<br>☐ Very easy<br>☐ Quite easy<br>☐ OK<br>☐ Quite hard<br>☐ Very hard | The pace today was<br>☐ Much too slow<br>☐ Too slow<br>☐ OK<br>☐ Too fast<br>☐ Much too fast |
| Please add any other comments overleaf. | |

**Figure A2.1.: Feedback Slip.**

### Responses

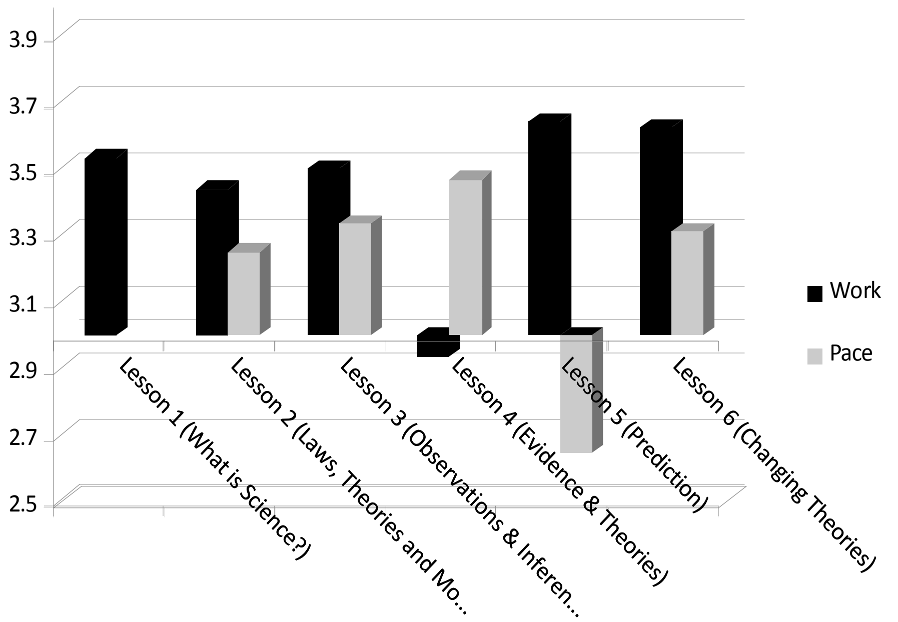
*Tick Boxes*

Analyses of the boxes ticked on the feedback slips received are shown below. Figure -Figure show the mean response from each lesson. Figure A2.2- A2.7-Figure show the frequency of each response across all lessons.




| | | |
|---|---|---|
| Lesson: | 5 | Today's lesson was very enjoyable |
| | 4 | Today's lesson was quite enjoyable |
| | 3 | Today's lesson was OK |
| | 2 | Today's lesson was not enjoyable |
| | 1 | Today's lesson was really not enjoyable |
| Topic: | 5 | Today's topic was very interesting |
| | 4 | Today's topic was quite interesting |
| | 3 | Today's topic was OK |
| | 2 | Today's topic was uninteresting |

**Figure.A2.2: Mean Responses on Feedback Slips for each Lesson (1).**




Key:

| | | |
|---|---|---|
| Work: | 5 | Today's work was very easy |
| | 4 | Today's work was quite easy |
| | 3 | Today's work was OK |
| | 2 | Today's work was quite hard |
| | 1 | Today's work was very hard |
| Pace: | 5 | The pace today was much too slow |
| | 4 | The pace today was too slow |
| | 3 | The pace today was OK |
| | 2 | The pace today was too fast |
| | 1 | The pace today was much too fast |

**Figure.A2.3 Mean Responses on Feedback Slips for each Lesson (2).**

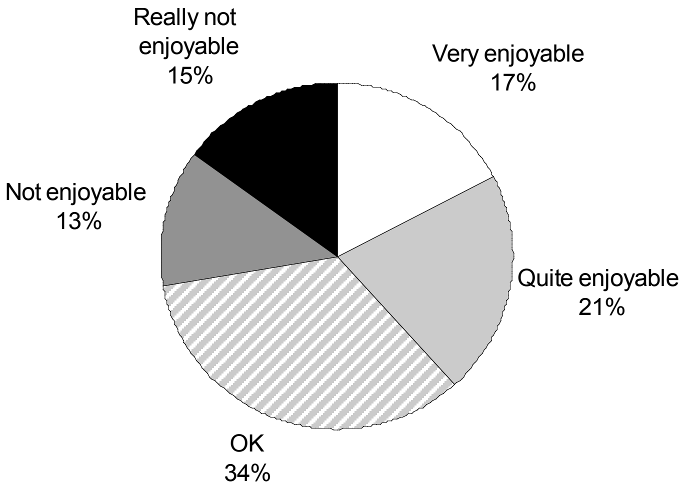



**Figure:A2.4 Responses to the Question "Today's lesson was…" across all Feedback Slips.**

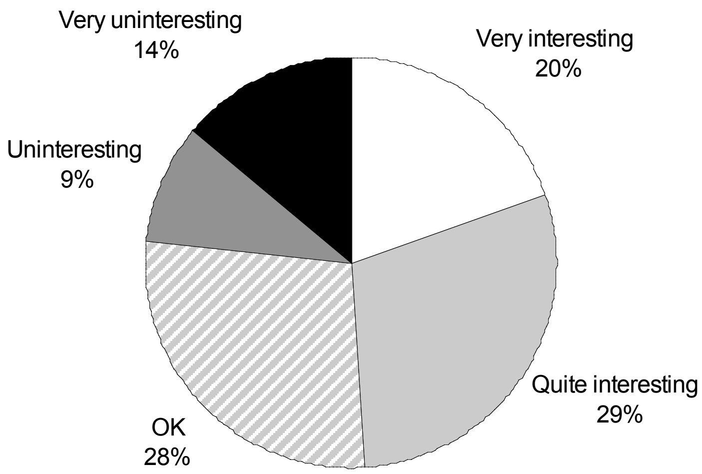



**Figure: A2.5 Responses to the Question "Today's topic was…" across all Feedback Slips.**

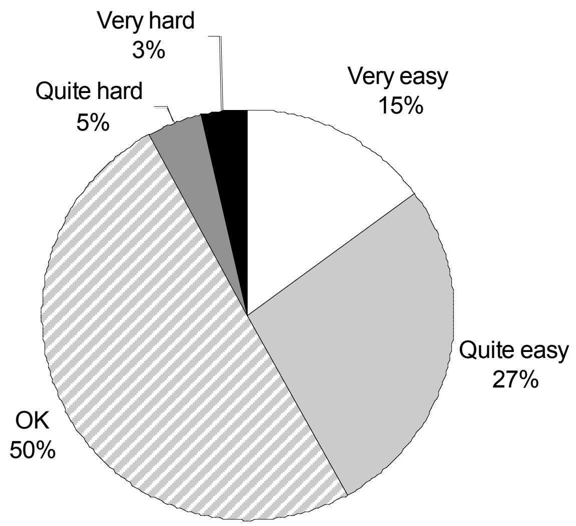



**Figure:A2.6 Responses to the Question "Today's work was…" across all Feedback Slips.**

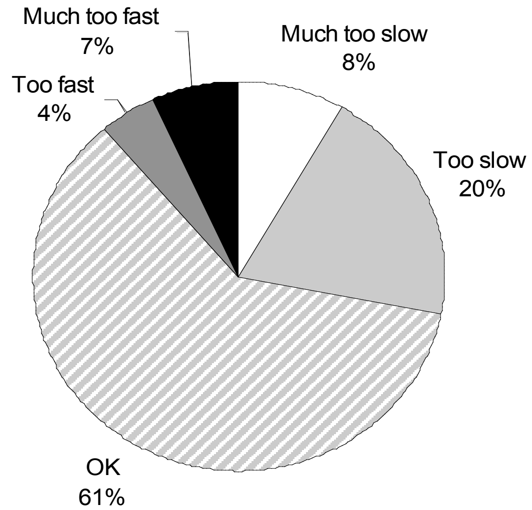



**Figure A2.7 Responses to the Question "The pace today was…" across all Feedback Slips in Lessons 2-6.**

## Appendix 3

**Quiz in Lesson 2 -The marks gained by students in the quiz in lesson 2 are shown in a cumulative frequency graph in Figure A3.1**

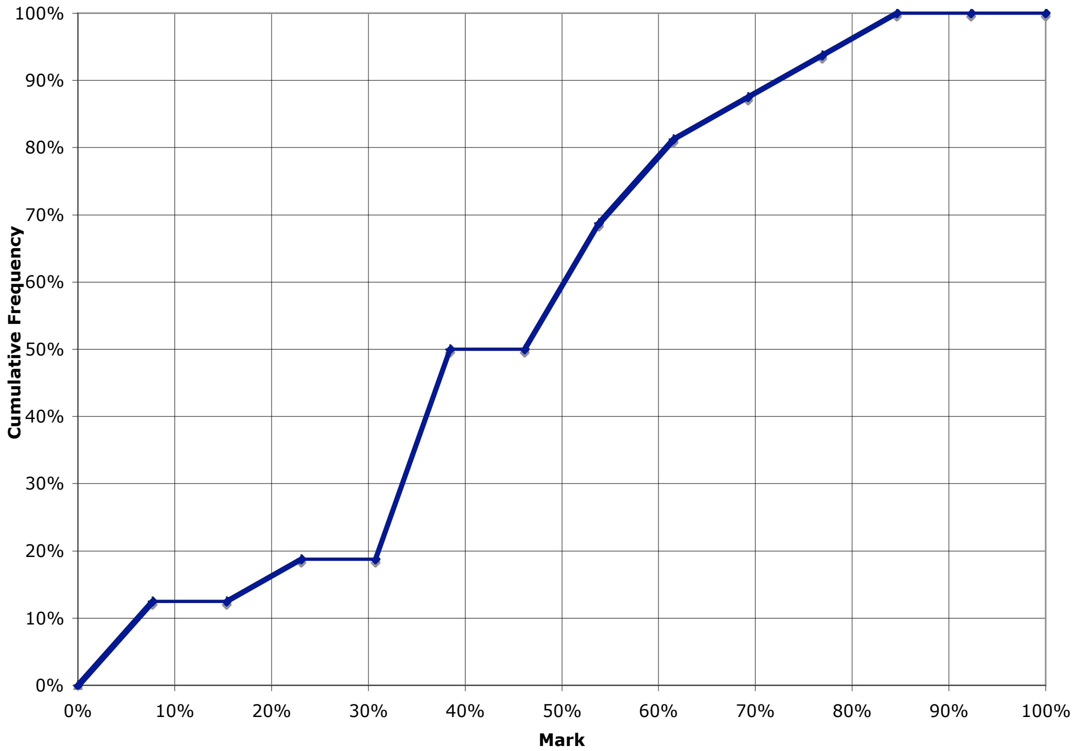



**Figure:A3.1 Marks gained in Starter Quiz in Lesson 2.**

## Appendix 4

### Post-Teaching Test

After the teaching sequence, the students took a test which comprised a standard end of unit test and some additional questions which were almost identical to questions 6-12 and 14-17 of the pre-teaching questionnaire. Seven students' end of unit test was a foundation tier paper (Harcourt 2006a; mark scheme Harcourt 2006b); 10 students took a higher tier paper (Harcourt 2006c; mark scheme Harcourt 2006d). The paper taken by a student was determined by the class' usual teacher and I, based on their previous end of unit test. In some cases, the students were given the choice about which paper they took.

**Additional Questions & Mark Scheme**

| | Questions | Mark Scheme |
|---|---|---|
| | | **HSW** |
| 1. | What is the purpose of a scientist's work? | Describe *or* explain (1) natural phenomena (1). (Words to that effect allowed in all cases.) |
| 2. | How are new scientific theories discovered? | Evidence *or* experiment *or* testing predictions *or* discovering something new *or* discovering something which doesn't fit with a current theory (1). |
| 3. | Is it possible to prove that a scientific theory (e.g. Newton's theory of gravity) is definitely correct? If it is possible, how would this be done? If it isn't possible, why not? | No (1) because one doesn't know whether new evidence will be discovered which disproves the theory *etc.* (1). |
| 4. | Sometimes scientists disagree with each other about whether a scientific theory is correct. Why do you think this is? | Evidence is inconclusive *or* wrong *or* different scientists have access to different evidence *or* as a process of critical review (1) and scientists may have personal commitments/biases (1). |
| 5. | When a scientist proposes a new theory, who decides whether the new theory should be accepted by all other scientists? | A consensus/majority of scientists *or* a journal (1). |
| 6. | Once a theory has been accepted by scientists, can it ever get changed or replaced by new a one? If this can happen, when would it happen? If it can't happen, why not? | Yes (1) if the new theory is supported by better evidence (1). |
| 7. | Are there any scientific ideas that you know about that you think might one day be replaced by better theories? | *Any sensible suggestion* (1). |
| | | **Space** |
| 8. | What is the difference between a planet and a comet? | Size *or* shape (1), composition (1) and shape of orbit (1). |
| 9. | What is a black hole? | The end-point of a star's life (1) which is very dense *or* has a strong gravitational force *or* which sucks things in (1). |
| 10 | What is an asteroid? | A rock (1) which orbits the sun (1). |
| 11 | Do stars ever stop shining? Why/why not? | Yes (1) when they run out of fuel (1). |

## Marks Gained on Additional Questions (Including Comparison with Pre-Teaching Marks)

**The marks gained on these questions before and after the teaching sequence are shown in**

Figure A4.1.

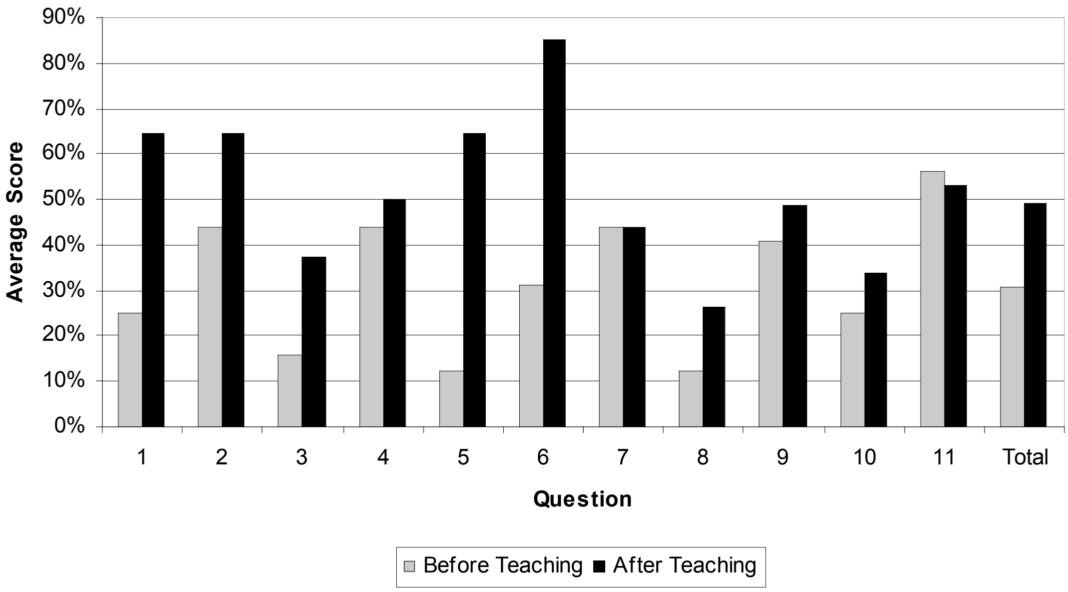



**Figure A4.1 : Marks gained on Test Questions Before and After the Teaching Sequence.**

## Appendix 5 Post-Teaching Questionnaire

The questions from the questionnaire the students completed after the teaching sequence are shown below, along with charts showing their responses (**Figure A1-Figure A5.6).**

1. We have spent a lot of time recently studying "How Science Works" (what theories are, how scientists use them, etc). Was it helpful to learn this material all at once, or would you have preferred to have it spread out through the year?

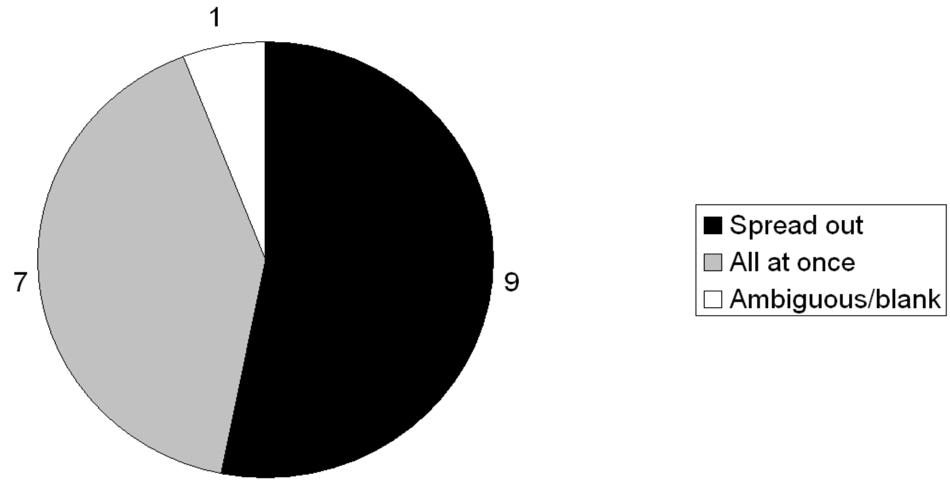



**Figure A1.1 Responses to Post-Teaching Questionnaire Q1.**

2. Did the fact that we were focusing on How Science Works make it harder to learn the space material?

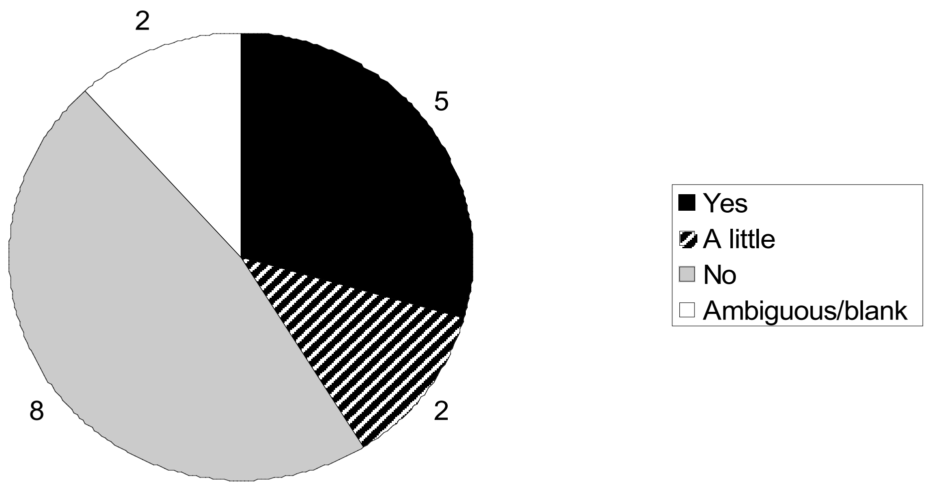



**Figure A5.2: Responses to Post-Teaching Questionnaire Q2.**

3. Was it confusing to learn about How Science Works and Space at the same time?

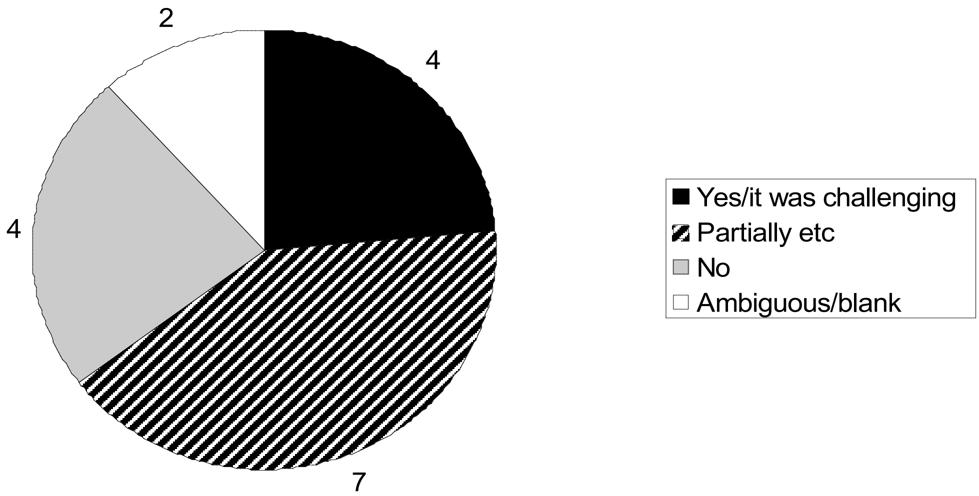



**Figure A5.3: Responses to Post-Teaching Questionnaire Q3.**

4. Did you find learning about How Science Works more or less interesting than learning about other science topics (e.g. space, electricity)?

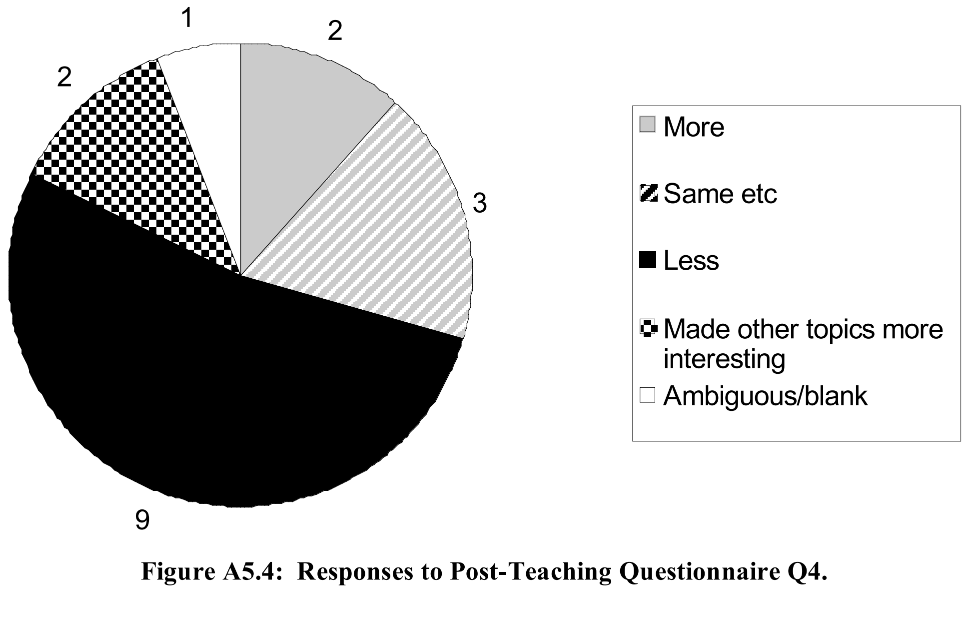
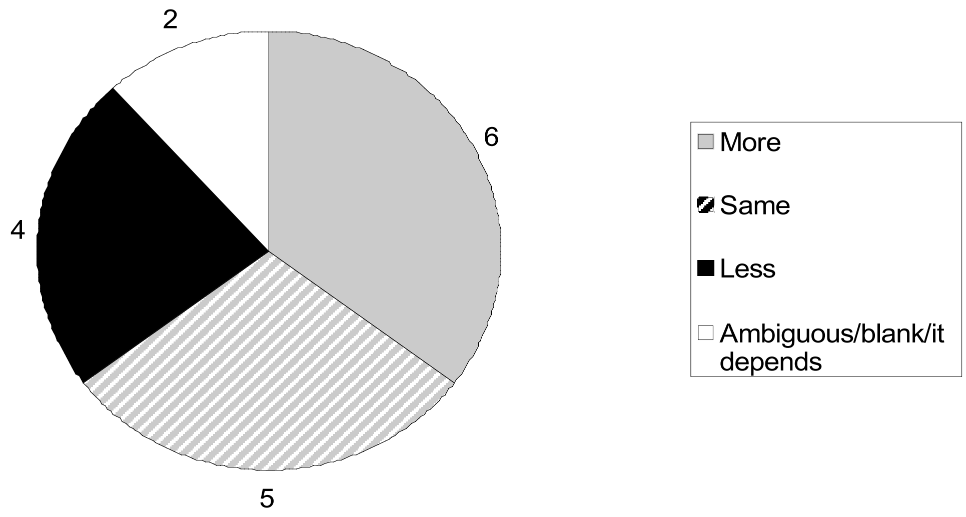



**Figure A5.4: Responses to Post-Teaching Questionnaire Q4.**

5. Do you think learning about How Science Works in schools is more or less important than learning about other topics? Why?




**Reasons given by those who said "More" or "Same":**

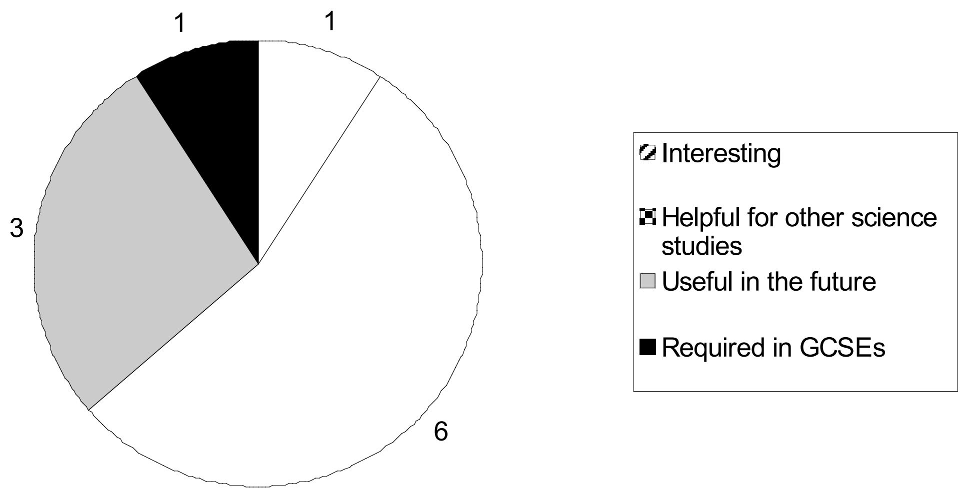



**Figure A5.5: Responses to Post-Teaching Questionnaire Q5.**

6. Do you think having lessons focussed on How Science Works has made you more or less motivated to learn science? Why?

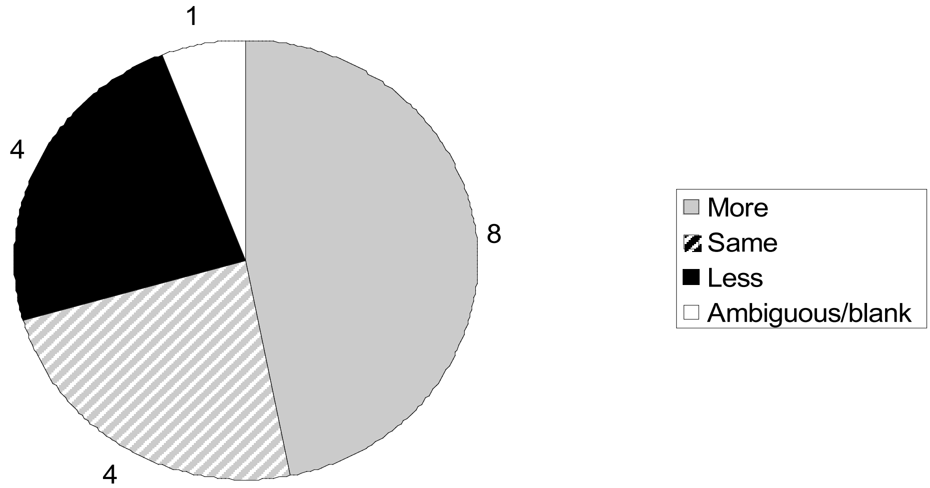



**Figure A5.6: Responses to Post-Teaching Questionnaire Q6.**