

The development of secondary school students' understandings of 'ideas about science'

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Abstract

This paper examines the development of students' understandings of 'ideas about science' using short, written response questions. Specifically, questions examine how students distinguish between correlation and cause in a science context. The responses of 178 secondary school students are examined at two points over an 18 month period (students aged 14 to 16 years). A small proportion of these students persisted in inferring a causal relation from a single co-occurrence. The quality of students' explanations for why a single co-occurrence cannot be used to infer a causal link improved over the period of the study. To examine trustworthiness 18 students' responses to these short written probes were compared with their verbal responses within a more open and extended interview context. Written responses were generally consistent with understandings communicated in the more extended interview setting. It is suggested that questions used in this study could be used by teachers in the classroom to provide reliable information about their students' progress at a level of specificity that would inform the design of subsequent teaching.

Introduction

Many current school science curricula place a considerable emphasis on achieving the educational goal of 'scientific literacy' (American Association for the Advancement of Science, 1993; University of York/Nuffield Foundation, 2004). Whilst this term has been variously defined a common theme is that of encouraging students to engage with science issues outside of school science contexts (DeBoer, 2000). Such curricula often emphasise learning about the development of scientific knowledge and the relationship between science and society. Following an influential analysis of the purposes and content of school science curricula we refer to such issues collectively as 'ideas about science' (Millar & Osborne, 1998). There is considerable evidence that students of all ages often exhibit inappropriate understandings of 'ideas about science'. Furthermore, there is growing evidence that many teachers find such teaching challenging (Bell *et al.*, 2001; Brickhouse, 1990; Lederman *et al.*, 2003; Osborne *et al.*, 2003). For example, classroom studies of teaching about the nature of theoretical models show that many teachers do not take account of students' initial understandings in this area (Ryder & Leach, in press).

Teachers will be better able to design and enact effective teaching of 'ideas about science' if they are aware of typical student misunderstandings in these areas. Previous studies have provided many insights into the thinking of students at different ages, and from different cultures (Bell *et al.*, 2001; Driver *et al.*, 1996; Germann & Aram, 1996; Germann *et al.*, 1996; Hackling & Garnett, 1992; Kang *et al.*, 2004; Rowell & Dawson, 1984; Solomon *et al.*, 1996). Findings in this paper add to this growing body of research. Short written response questions that give valid insights into students' thinking can also support teaching in this area. Such questions can be used by teachers to probe their students' developing understandings of 'ideas about science' in the classroom. Insights from students' responses can be used to guide

the design of subsequent teaching (Black *et al.*, 2003). There is also evidence that teachers, and students, are often unclear about the learning aims of teaching activities related to ‘ideas about science’ (Hind *et al.*, 2001). The use of short written questions within the classroom can provide students with a clear view of what ‘ideas about science’ it is intended they learn within the course. Written questions can also contribute to the assessment of student learning at the end of a science course (as part of course evaluation studies and also formal external testing of students). However, many of the available probes of student understanding of ‘ideas about science’ have been developed as research tools rather than for use in the classroom (e.g. Driver *et al.*, 1996; Lederman *et al.*, 1998). Whilst such probes can be used by teachers, they may require considerable classroom time for students to complete. Analysis of responses by teachers may also require significant time. As a result there is a need for short, written response questions probing understanding of ‘ideas about science’ suitable for use by teachers in the classroom.

In response to the challenges raised above this paper examines responses to short assessment items that could be used by teachers for assessing students’ understanding of specific aspects of ‘ideas about science’. Several issues are addressed. Firstly, what do these short, written response items reveal about student understanding of key aspects of ‘ideas about science’? Secondly, what does the repeated use of these assessment items reveal about the development of students’ understandings over an 18 month period? The paper also examines the extent to which student understandings of ‘ideas about science’ elicited using short written response probes are consistent with their verbal responses within a more open and extended interview context.

Methodology

This paper focuses on the development of students’ understandings of specific ‘ideas about science’ over an 18 month period. Findings are drawn from a larger evaluation study addressing the development of students’ conceptual and procedural knowledge (Scott *et al.*, 2005). Results for one of the questions used in this study (Skin Cancer) are presented here. The Skin Cancer question has two parts. The first part of the question examines how students interpret statements of risk. This paper focuses on the second part of the Skin Cancer question which examines whether students interpret a single case linking two factors (i.e. a co-occurrence) as indicating a causal connection. Students provide a yes/no closed response and are then asked to explain their answer in an open response. The full text of the question is provided in the appendix. Figure 1 summarises the intended focus of part 2 of the Skin Cancer question.

Question	An appropriate answer would include some or all of the following elements:
Skin Cancer (part 2)	<ul style="list-style-type: none"> • reference to some possible causes of headaches (e.g. dehydration, stress); • recognition that a causal link cannot be inferred from a single co-occurrence; • reference to the significance of sample size and/or control of variables in the design of scientific investigations.

Figure 1 Summary of the focus of part 2 of the Skin Cancer question

Implementation

The Skin Cancer was incorporated into a questionnaire booklet containing 7-8 questions. The additional questions probed student understanding of science subject matter (e.g. infra-red radiation, global warming) and other areas of ‘ideas-about-science’. These were included as part of a longitudinal, comparative study of students’ developing understanding of science (Scott et al., 2005). Questionnaires were sent to schools in Autumn 2004 and again in Spring/Summer 2006. Schools were selected to provide a range of achieved academic standards, school type (e.g. rural/urban, selective/non-selective), school size and geographical location within England. Schools were requested to distribute the questionnaires to a specified number of Y10 science groups (students aged 14-15 years old) at the beginning of the school year. A total of 178 students from a wide ability range were asked to respond to the Skin Cancer question on two occasions: at the start of Y10 and the end of Y11. These students are taken from 15 schools in England.

It is possible that terms used in open written responses will be misinterpreted by the researcher. In this study an additional sample of 18 students provided verbal responses to the Skin Cancer question during individual interviews with the author. These 18 students were chosen from two Y10 classes in one school to represent the full ability range at that school. Interviews were held one week after the students had given written responses to the Skin Cancer question. Each interview lasted around 10 minutes. In the interviews students were not shown their earlier written response. Rather they were asked to provide a new, verbal, response to the question. Following each response students were encouraged to elaborate upon their answer and explain key terms. It is possible that many students’ ideas about aspects of the nature of science will be unstable and incoherent (Sandoval & Morrison, 2003). Students were also given the opportunity in the interview to state how sure they are about their responses.

Findings

The Skin Cancer question includes a newspaper extract quoting a member of the public saying that he would not now use a particular brand of sun protection cream because he had suffered a bad headache soon after using the cream. Students were asked to indicate ‘yes/no’ whether this person’s experience shows that using this sun protection cream causes headaches. Table 1 shows the frequencies of these closed responses.

	Start of Y10 (number of students)	End of Y11 (number of students)
Correct response (NO)	151	141
Incorrect response (YES)	17	5
No response	10	32
TOTAL	178	178

Table 1 Closed responses to Skin Cancer (part 2)

Table 1 shows that there were a high number of students who did not provide a closed response in the questionnaire given at the end of Y11. To examine the development of

individual student responses Table 2 provides a transition matrix for the 138 students who provided a closed response in Y10 and again in Y11.

Number of students	Y11 Correct	Y11 Incorrect
Y10 Correct	124	2
Y10 Incorrect	9	3

Table 2 Transition matrix for closed responses to Skin Cancer (part 2)

Most of these students (90%) chose the correct response at Y10 and again at Y11. Table 2 shows that 7% of the students improved from an incorrect to a correct closed response from Y10 to Y11. These findings suggest that a small proportion of these students (4% at the end of Y11) chose responses reflecting incorrect reasoning that a single case linking two factors indicates a causal connection. This outcome can be compared with those reported by Kuhn et al. (1988). As part of a larger study students were asked to interpret data about the impact of different foods on whether or not children get colds. In interviews they found that around a quarter of the students (aged 11-16 years old) inferred a causal link between food type and 'getting a cold' based on a single co-occurrence.

Students were also asked to provide a written open response to explain their answer. The following response shows a student reasoning incorrectly that a single case linking two factors can indicate that one factor causes the other:

The headache started soon after using the cream so that is what caused the headache.

By contrast the majority of students gave appropriate explanations for why this single case *did not* indicate that using the sun cream caused the headache. The findings below focus on the open responses of the 124 students who provided a correct closed response to the Skin Cancer question in Y10 and Y11. The analysis examines whether or not the *quality* of open response explanations changes from Y10 to Y11, for these students.

Appropriate explanations focused on the need for more data and/or the presence of additional factors that might have caused the headache. Data-focused responses included students stating that this person needed to use the sun cream more times and check if this causes headaches. Data-focused responses also identified the need for different people to use the sun cream:

Not enough data

Need to try it with more people

The person needs to try it several times

Table 3 shows the proportion of students including a statement coded as ‘data-focused’ in their response. The proportion of students making these statements increased from the start of Y10 to the end of Y11.

(n=124)	Start of Y10 (% students)	End of Y11 (% students)
Data-focused	28	34

Table 3 Data-focused open responses

Explanation-focused responses identified the importance of considering other factors that might have caused the headache. The following responses make a general statement about other factors without providing an example:

Could be other factors involved

Caused by something else

The responses below are more specific in that they provide one or more examples of potential other factors:

Could have been caused by dehydration/illness/bug

Too long in the sun, too hot

Table 4 shows the proportion of students including a statement coded as ‘explanation-focused’ in their response. Again, the proportion of students making these statements increased from the start of Y10 to the end of Y11.

(n=124)	Start of Y10 (% students)	End of Y11 (% students)
Explanation – focused	48	58

Table 4 Explanation-focused open responses

Table 5 provides a more detailed analysis of explanation focused responses, showing the proportion of students who included specific causes in their response.

(n=124)	Start of Y10 (% students)	End of Y11 (% students)
General reference to other causes	27	23
Specific causes mentioned	21	35

Table 5 More detailed analysis of explanation-focused open responses

Of these 124 students 6% provided both a data-focused *and* an explanation-focused response at the start of Y10, rising to 10% at end of Y11. Other responses coded as ‘coincidence’ or ‘no proof’ used these terms but provided no further explanation, e.g. ‘*it might just be a coincidence*’.

For the sample of students participating in interviews all 18 students stated in both the written questionnaire and interview that the person’s experience did NOT show that using the sun protection cream causes headaches. The comparative analysis of students’ written and verbal explanations is presented in Table 6.

Category of response	Number of students (N=18)	
	Interview	Written
Data-focused	14	6
Explanation-focused	15	12
Coincidence/no proof	3	4
Other	0	0
Incorrect reasoning	0	0
No response	0	1

Table 6 Coding of interview and written responses for part 2 of Skin Cancer question

A significantly larger proportion of students suggested in the interview that it was necessary to gather more data, either for this person or a larger sample of other people. However, five of these statements given in the interview were the result of a prompt question used after the students’ initial responses: ‘what would need to be done to be clearer about whether or not the sun cream causes headaches?’. This question is not used in the written questionnaire. As a

result the form of this questionnaire results in an under-representation of students' ideas within their written response. The extended interview context enabled students to demonstrate additional reasoning.

Discussion

A stated aim of many current school science curricula is to promote students' engagement with science in contexts outside of formal science education. Developing students' understanding of 'ideas about science' is often seen as an important step to achieving this aim. The study reported in this paper involved students in their final two years of compulsory school science education. A small proportion of these students concluded that a single case linking two factors indicated that one factor caused the other. Such erroneous statements are often used in the news media when reporting scientific findings. In line with previous studies (e.g. Kuhn et al., 1988) the results in this paper suggest that a small proportion of students may not recognise such reasoning as inappropriate.

The use of supplementary interviews with a small sample of students revealed several issues. Overall, these interviews showed that students generally gave a verbal response that was consistent with their earlier written response. This suggests that this short question, used in written form, provide effective insights into students' thinking. Indeed, some students provided near identical responses in their written and verbal answers. However, for some students, whilst ideas present in the written responses are repeated in interviews, the interviews also provide *additional* reasoning. For example, the use of an additional prompt question within the interview resulted in a significantly higher proportion of students exhibiting 'data-focused' reasoning. This finding is consistent with previous studies that have shown that written responses can *underestimate* students' ideas about the nature of science (Lederman & O'Malley, 1990; Ryder & Leach, 2000; Southerland et al., 2005).

Findings in this paper could be used by teachers to inform the design of teaching activities that address specific student misunderstandings of the 'ideas about science' examined here. However, the views exhibited by the students in this study may not be reflected in responses from students from other cultures/countries, following distinctive science courses. The more significant contribution of this study might therefore be the presentation of tried and tested questions amenable for use by teachers in the classroom for both formative and summative assessment of student understanding. The question used in this study required only 2-5 minutes for completion by students. Furthermore, with access to the coding scheme teachers could rapidly analyse the performance of the students in their class. As a result, the question reported in this paper could be used by teachers in the classroom to provide reliable information about their students' progress at a level of specificity that would inform the design of subsequent teaching.

Further research

Further question development is needed in other areas of 'ideas about science' in a broader range of science contexts. However, it is important that such questions have a high level of specificity (in terms of science content area and aspect of 'ideas about science' being addressed). The usability of these questions also needs to be assessed for students of differing ages and abilities, and in different countries and cultures. Furthermore, such studies need to consider the trustworthiness of students' written responses, for example by conducting follow-up interviews with a sub-sample of students. These questions can then be employed in cross-sectional and longitudinal studies to address developmental aspects of student understanding of 'ideas about science'. Studies also need to consider the extent to which students' responses relate to their *activities* inside the classroom (Millar et al., 1994). Of considerable interest given the focus on 'scientific literacy' (but also much more challenging

methodologically) is how student's responses relate to how they engage with science outside of formal education.

One of the characteristics of the question used in this study is that it can readily be used by teachers in the classroom. An important issue for further investigation is how teachers use such questions as part of their teaching. For example are questions used as elements within summative assessment or are they used to inform the development of a lesson or teaching sequence, i.e. as a formative assessment tool? Are teachers able to adapt the format and/or context of questions to suit the ability of their students and the science content focus of their lessons? Do teachers who make such adjustments do so whilst maintaining the 'ideas about science' focus of the question? What professional development activities might inform teachers' appropriate use of such questions?

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Appendix: Skin Cancer Question

A newspaper article claims that in the UK the chances of a person developing skin cancer in their lifetime is **1 in 10**. If this claim is correct which of the following conclusions can be drawn?

Place a tick in the appropriate boxes to show what you think.

	This <u>is</u> a reasonable conclusion	This <u>is not</u> a reasonable conclusion
In a class of 20 students, we can be sure that 2 will develop skin cancer in their lifetime.		
One member of a group of 10 friends develops skin cancer. This means that the other 9 friends will definitely not develop skin cancer.		
In a city of 1,000,000 inhabitants, around 100,000 will develop skin cancer.		

The newspaper article goes on to say that you can reduce the chances of getting skin cancer by using sun protection cream. However, one member of the public interviewed by the newspaper made the following statement:

'I used a particular brand of sun protection cream this Summer – it was called ScreenZone. I used it one weekend and I had a really bad headache on the Monday. I've not used it since!'

Does this person's experience show that using ScreenZone sun protection cream causes headaches? (Please tick one response).

	TICK
Yes	
No	

Please explain your answer as fully as you can: