UNIVERSITY PHYSICS STUDENTS' EXPLANATIONS OF SUNLIGHT

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ABSTRACT

We examine third year university physics students' use of models when explaining the emitted solar spectrum and the apparent colour of the sky. The explanations involve interaction between sunlight and the atmospheres of the Sun and of the earth. A range of scientific models are available to explain these phenomena. However, explanations of these phenomena tend not to be used as exemplars of scientific models within undergraduate physics education. The student sample is drawn from six universities in UK and Sweden. These students have difficulties in providing appropriate explanations for the phenomena. Many students draw upon the refraction of linear rays when explaining the colour of the sky on a sunny day. Few students use a single model consistently in their explanations of these related phenomena. Students' use of models appears to be highly sensitive to the context in which the phenomena to be explained is presented to them.

1. INTRODUCTION

There have been a number of papers considering teaching and learning in specific content areas of university physics [1-11], but not for the area of interactions between matter and electromagnetic radiation. We have performed an exploratory study in this area and looked at university physics students' explanations of certain phenomena. We examine the models that students use in their explanations, and consider the extent to which these models match the science models typically taught at this level. A key feature of the study is students' use of scientific models to explain familiar phenomena. Our view on the relationship between phenomena and models are that of Giere [12]. In this report we discuss the phenomena involving interaction between sunlight and atmospheric particles. A more thorough presentation of the project can be found in [13] where the main part of the study concerning the interaction of metals and electromagnetic radiation is reported.

It has been suggested that acquisition of conceptual understanding in science is influenced by views about the nature of science. The concept area of interactions between matter and electromagnetic radiation has a large number of explanatory models available and therefore provides a valuable context in which to explore the relationship between university students' views about the nature of scientific knowledge and their development of conceptual understanding [14-16].

An additional interest informing the design of our study was the context-dependence of the models drawn upon by students. Engel et al. [17] provide evidence that many school age students do not apply conceptual models consistently across contexts. Mortimer [18] has suggested that rather than a single conceptual understanding, students exhibit a 'profile' of conceptual understandings. Other work suggest that students hold a range of co-existing conceptions, of differing strength and status [19-20]. To explore these considerations our study included an analysis of the consistency of students' use of models in explaining the interactions between metals and electromagnetic phenomena.

2. METHODOLOGY

Students were asked to provide written explanations of phenomena. A written survey enabled us to use a sample large enough to reflect the range of models used in explanations by students at this level. Since the phenomena in the survey can be explained using a number of different explanatory models of differing degrees of sophistication, we chose to use open response questions in the survey. This ensured that students were not guided towards particular explanatory models presented to them. We also conducted follow up interviews, with demonstrations, for a subset of the student sample. Interviewees were asked to give a verbal response to each of the written questions. These interviews were used to assess the validity of the written survey responses, and to provide details of individual student's explanations across the phenomena presented in the survey.

3. STUDY DESIGN

We report findings for a subset of questions included in a broader survey of university students' explanations of phenomena involving the interaction between electromagnetic radiation and matter. All the phenomena are familiar to the students. The phenomena focused on in this report involve sunlight, henceforth called the *Sunlight Sequence* (table 1). The full survey can be found in [13].

Initial versions of the written survey were piloted with 38 students. These students were in their first or second year of university in England or Sweden. In addition, pilot interviews were held with two Swedish and three English students. In the pilot interviews students were shown demonstrations. The survey and interview schedules were modified and shortened following piloting. The pilot interviews indicated that the written survey responses were providing a valid indication of students' views. However, piloting showed that the questions were too advanced for many first and second year students. In order to ensure that the students would have been introduced to all relevant models, third year university students were used for the final survey.

Table 1. The phenomena of the Sunlight Sequence.

Short title	*Phenomenon to be explained*
Solar spectrum	The occurrence of absorption lines in a spectrum of the Sun
Blue sky	Why the sky appears blue on a sunny day
Red sun	Why the Sun appears red as sunset approaches

In order to reduce the impact of any specific teaching sequence our final sample included students at several universities. We collected 74 written responses from two universities in England and four in Sweden. We interviewed nine of these students: two in England and seven in Sweden. We aimed at a sample large enough to capture the main explanatory models used by students. We were concerned to establish that previous courses taken by these students included the models we identify as appropriate explanations of the phenomena presented in the survey.

4. RESULTS

4.1 An overview of students' responses

To provide a preliminary overview of the data we conducted a normative analysis of students' responses to each of the questions. Each response was coded as 'appropriate', 'insufficient detail', 'inappropriate' or 'no response'. Appropriate explanations for each of the three phenomena needed to include both of the following features:

1. Recognition of the dominating process, e.g. absorption for the solar spectrum and scattering for the colour of sky and sun.
2. Some reference to gas or dust particles as being active in the absorption or scattering of photons.

Responses coded as *'insufficient detail'* do not provide enough description of the matter-radiation interaction to satisfy both criteria for the 'appropriate' category. Statements leading to contradictions or not conforming to observations are coded as *'inappropriate'*. These included responses referring to destructive interference of light as the source of the Fraunhoffer absorption lines, and statements identifying refraction as the dominating process behind the appearance of sky and sun. Table 2 summarizes the results of this normative analysis for each of the phenomena in the sunlight sequence.

Overall, table 2 shows a low proportion of student responses giving an appropriate explanation. Only about a third of the student sample for the last two phenomena. This is noteworthy given the weak criteria for an appropriate answer. Finally, the fact that an absorption spectrum often appears in introductory quantum physics courses could explain why a higher proportion of students use an appropriate model in this context, still it is less then two thirds of the students.

Table 2. A normative analysis of student responses for each phenomenon in the sunlight sequence.

	Number of students (n=74)			
Short title	*App.*	*Insuff. detail*	*Inapp.*	*No resp.*
Solar spectrum	45	14	11	4
Blue sky	24	12	33	5
Red sun	21	11	36	6

4.2 Models used by students in their responses

In order to examine the details of the models of matter-radiation interaction drawn upon by students we conducted a second, ideographic analysis. Data was examined with a commitment to reflecting each student's position as written, rather than evaluating a particular response in terms of a set of normative positions. The categories are described below. Each category is exemplified using survey responses.

AB ***Absorption process***
A model of quantised absorption of photons is used. The photons are reemitted in other directions.
'The molecules in the upper part of the atmosphere have excitation energies corresponding to blue light and when they de-excite the sky looks blue.' (Survey, blue sky)

SC ***Scattering process***
A photon model is used for the light and elastic scattering with free particles is discussed as the dominating process.
'A Rayleigh scattering cross-section in atmosphere where frequency of incident radiation < natural frequency of molecules in the air goes as $\sim\omega^4$ *- Blue light at higher frequency has much lager cross-section of interaction than red so will be scattered more readily..'* (Survey, blue sky)

IN ***Interference process.***
A wave model is used for the light, interference and/or diffraction is discussed in the explanation.
'Light acts as a wave. We know that when a wave encounters another wave out of phase, they will interfere destructively. This creates the black lines' (Survey, solar spectrum)

RE ***Refraction process***
Here there is often no mention of free particles and a linear ray model is used for the light.
'White light refracts in the atmosphere and is divided into different wavelengths. The red is refracted least and reaches our eyes' (Survey, red sun)

EM ***Emission process***
This category captures responses that describe excitations of bound electrons and emission as the dominant process.
'The gaps in the spectrum show that a certain element is missing from the Sun. That is, all wavelengths of visible lights are emitted by the Sun except the ones indicated by the dark bands. We can say this because we know that light can only be emitted in discrete wavelengths' (Survey, solar spectrum)

Coherent responses not represented by any of the above categories were coded as *'other'* (OT). Responses from which it was difficult to understand what the student was saying, or which were very brief, were coded as *'vague response'* (VR). Finally, student responses stating that they could not provide an answer were coded as *'do not know'* (DK), and null responses as *'no response'* (NR).

The categorisation of statements in the interview transcripts matches that of the written responses for all the interviewees. This supports our view that the written survey responses as a whole are successful in capturing the general features of students' explanations.

Table 3 shows, question by question, the number of student statements from the written survey in each of the categories described above. Analysis earlier showed a high proportion of inappropriate answers for the blue sky and red sun phenomena (see table 2).

Table 3. Results from the ideographic analysis of the written survey responses.

Categories		*Solar spectrum*	*Blue sky*	*Red sun*
AB	*Absorption process*	54	16	7
SC	*Scattering process*	1	34	28
IN	*Interference process*	7	-	-
RE	*Refraction process*	-	14	23
EM	*Emission process*	3	-	-
OT	*Other*	-	3	3
VR	*Vague response*	5	2	7
DK	*Do not know*	-	2	1
NR	*No response*	4	3	5
Totals		74	74	74

Table 3 shows that these inappropriate responses are largely accounted for by students discussing in terms of absorption and refraction processes. There is an increase in the number of students using linear ray models and refraction in explaining the red sun compared to the blue sky. This context dependence could partly be explained by the fact the refraction actually do come into play for low solar altitudes. However, it is not a process that students at this level are expected to use in order to explain why the sun appears red at sunset.

4.3 Interview responses

In addition to providing validation of the written statements, student interviews also give more details of individual student's explanations across the phenomena in table 1. The following quote is part of the interview response from a student to the *Red Sun* question. The quote shows a student struggling to incorporate a 'remembered' lecture.

Student *This has been explained to me during my first physics semester. The Sun is here and we have a refractive index in the atmosphere increasing towards the surface of the earth, which means that the light at sunset will be refracted towards the surface and red light is refracted more than blue, no vice versa, no no red light is bent more than blue which means that the blue ... No I do not know. I wanted to explain that you only get one of them.*

Interviewer *Well, I guess we already know that. We know that it looks red, right?*

Student *Ok, yes. (Drawing of sunset situation) Here is the Sun and radiation is emitted. This is what we see and we think then that the Sun is here, but it is here. The last thing we see ... I do not really know, either the blue or the red is refracted most, but if the red is refracted more we will see the blue later and it should turn blue before disappearing. Maybe it does and we just do not see it because it has the same colour as the background, or the blue is refracted most and then the blue is gone when we see the red, which I believe more strongly in. You could also explain it as above* [Blue sky], *simply that all colours except red has been scattered away from the direct light when the Sun sets, but I know it has to do something with refractive index, and ...*

Interviewer *Ok, this means that we have a choice of two explanations, or?*

Student *Yes, but I want to keep the refractive index one, because I have had that explained to me. I think the other one is very logical, but ...*

This supports the suggestion by others [19-20] that students hold a range of co-existing conceptions of differing strength and status. This student seems to realise that a scattering process is needed in the explanation but struggles because of the 'remembered' lecture.

4.4 Analysis of consistency

The design of the Sunlight Sequence allows for tests of consistency in students' responses. The last two questions (blue sky and red sun) present contexts in which the process is the same: *a frequency dependent scattering of sunlight by small particles*. The only difference is the altitude of the sun. We define a consistent response to these questions as one that uses the same model of scattering in the explanations.

After having analysed the written responses we found that only slightly more than half of the students (41 of 74) use the same model in explaining the blue sky and red sun phenomena. Only 21 of these 41 students gave appropriate responses, as defined earlier, the rest were consistently using an inappropriate model.

5. DISCUSSION

5.1 Subject matter knowledge

Few of the university physics students in our sample were able to provide appropriate explanations for the phenomena of the Sunlight Sequence. Table 2 shows that students struggled to articulate a coherent and complete explanation of the physical processes in the *Blue sky* and the *Red sun* phenomena. Even though scattering processes have been covered in courses taken by the students. Many students think of refraction and prism when faced with having to explain the appearance of a blue sky. They appear not to have learned to appreciate the limitations of a linear ray model, and they seem untroubled by having to use a different model or to twist things around in order to explain also the red sun.

5.2 Context dependence of students' responses

Our study provides additional evidence for the claim that individual students are able to deploy a range of scientific models in a single content area [17-20]. Despite the close relationship between the last two phenomena in our study only 41 of the 74 students in our sample deploy a single model across these contexts. Closer examination suggests that students' use of models is influenced by details of the context in which the phenomena are presented to them.

5.3 Implications for future teaching and research

As suggested by earlier studies of conceptual understanding the context dependence of student explanations has implications for research studies in this area. In particular, that a student draws upon a naive scientific model in one context does not necessarily mean that they cannot draw upon more sophisticated models in other contexts [19-20]. In the study reported here, there were indications in some interviews that students were considering using a more sophisticated model than their original response, but they were clearly reluctant to do so in the interview setting.

Similarly, Roth (2000) found that students reverted to rote recall when asked to make new connections in an unfamiliar context. This suggests that introducing students to models using a set of exemplary contexts will not necessarily lead them to draw on these models in other contexts. Of course, teaching using exemplary phenomena is an important first step as students begin to understand the key elements of a model. However, we suggest that such teaching needs to be followed by using the model to explain an extended range of phenomena. Of particular importance in a teaching sequence might be phenomena for which the model *cannot* provide a complete explanation, i.e. contexts in which limitations of the model resulting from inherent assumptions and approximations are exposed. For example, a model of light as linear rays cannot explain the scattering of light in the atmosphere.

In this way students come to recognise the breadth of contexts in which particular models can be applied appropriately. Such teaching might be accompanied by more explicit teaching about the nature of models [12]. Many studies have highlighted the relationship between conceptual understanding in science and views about the nature of scientific knowledge [14-16]. Future studies could track the development of students' understanding in response to a teaching unit that incorporates both explicit discussion about the nature of models in science, and teaching about the many models of matter and their use in explaining the EM interactions. A key question for such a study would be the extent to which students are able to make links between these two foci of the teaching. The aim of such teaching would be to provide students with 'meaningful learning' about EM interactions, i.e. learning that students can relate to their personal experiences and prior knowledge [22]. In particular, meaningful learning in this context involves recognition of the distinction between the world of models and the world of phenomena, and the assumptions and approximations within models that limit the contexts to which these models can be applied effectively.

6. REFERENCES

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