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Physics Teachers' Perceptions of the Difficulty of Teaching Electricity

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Abstract As part of a project concerned with developing a better understanding of the detail of appropriate teaching of direct current (DC) electricity concepts, extensive individual interviews were conducted with a number of experienced senior high school physics teachers. These interviews explored teachers' perceptions of difficulties in student learning and their own teaching of DC electricity, their uses of models and analogies in this teaching, and their own understandings of the concepts of DC electricity. Eight high school physics teachers from the Australian state of Victoria were interviewed: three who had a strong focus on student understanding in their classrooms and five who used more traditional approaches. We also interviewed three authors of textbooks then currently used in senior high school physics in Victoria, all of whom were also teachers of high school physics. All but one of these eleven interviewees was a very experienced teacher of DC electricity at the senior high school level. The interview data are summarized and implications for curriculum and teaching/learning of electricity are considered. There was a wide range of views among the teachers about the difficulties of both the concepts of DC electricity and the teaching of these concepts, and about the nature of physics knowledge. A number of the interviewees revealed levels of conceptual understanding that we see as of concern. Some of the teachers whose understanding causes us concern made clear early in the interview their view that the concepts of DC electricity were essentially straight forward; in all cases these interviewees had by the end of the interview reconsidered this position.

Keywords Physics teaching · Electricity · High School

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Introduction

There is an extensive literature about student ideas and beliefs ('alternative conceptions') about direct current (DC) electricity. Investigations have involved young children (e.g. Cosgrove et al. 1985; Shipstone 1985), senior high school students in specialist physics subjects (e.g. Dupin and Joshua 1987; Eylon and Ganiel 1990; Koumaras et al. 1997), undergraduate and postgraduate physics students (e.g. McDermott and Shaffer 1992; Viennot and Rainson 1992), teachers of science and physics (e.g. Ameh and Gunstone 1985; Cohen et al. 1983; Pardhan and Bano 2001; Tabanera 1995), and comparisons of novices and experts (Stocklmayer and Treagust 1996). The understanding of DC electricity by learners of all ages before any formal learning experiences is highly idiosyncratic, strongly influenced by everyday uses of words such as: "power", "flow", and, especially, "voltage", very commonly in conflict with the conceptions of physics, and frequently little changed by conventional teaching sequences. Student abilities to complete algorithmic (and only algorithmic) DC circuit problems are often enhanced by teaching, but little else appears to develop in these situations. There are a number of reviews of this extensive body of work, and we do not attempt any further form of summary here. Examples of reviews and commentaries with differing perspectives include Duit, Jung and von Rhöneck (1984), Duit and von Rhöneck (1997/1998), McDermott (1997/1998), Psillos (1997/1998), Schwedes and Schmidt (1992), and Shipstone (1985).

We have previously argued (Mulhall et al. 2001) that there are two essential reasons for such strong concern with DC electricity in research on alternative conceptions.

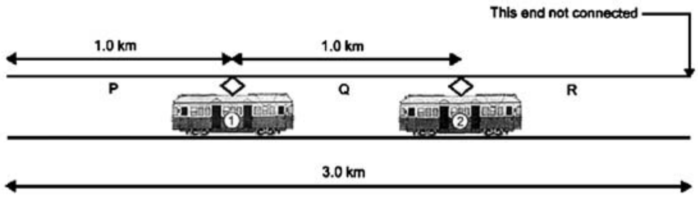
> The first reason is that electricity in some form is seen as a central area of physics/science curricula at all levels of education, primary, secondary and tertiary. The second reason… is that the concepts of electricity are particularly problematic – these are highly abstract and complex in ways that make their understanding both centrally dependant on analogies and metaphors and frequently problematic. (p 576)

In that paper (Mulhall et al. 2001) we also showed that studies of conceptual change in electricity involving alternative content sequencing and/or teaching and/or assessment approaches had clearly variable results, and, more importantly, researchers in this field offered conflicting interpretations of what research has to say about teaching for better student understanding of electrical concepts. We also gave examples of both inadequacies in teacher understanding, and confusions in language use and conceptions in physics textbooks.

A further example of the confusions, both conceptual and pedagogical, that characterize this area of physics is a question from a high stakes senior high school physics examination (end of year 12, university entrance) in the Australian state of Victoria, the site of this research. The question was used around the time of the collection of the data reported in this paper, and was intended to assess student learning about the section of year 12 Physics on electric power. It is shown in Fig. 1. This question was generated by a panel of examiners that included a number of academic physicists. The reference in two spots to the voltage at a point is in conflict with the general approaches (and, specifically, previously sanctioned-by-curriculum approaches) in Victoria to conceptualize voltage in terms of a difference between two points. More fundamental is that while the question cannot be answered unless one assumes the tram track to be at zero potential (earth), at the same time one must see a potential difference between the ends of the tram track in order for the current to "return through the rails." There is no indication in the question of assumptions such as these that must be made in order that an analysis of the situation can be undertaken.

AREA 2 – Electric power

The electric power for Melbourne trams is supplied at a DC voltage of 600 V. The current flows from the overhead wire through the tram motor and returns through the metal rails. Because of the voltage drop that occurs in the overhead wire, the wire is made up of separate 3.0-km sections. One of these sections is shown in Figure 1. A separate 600-V supply is connected to **one end only** of each section.



Tram 2 is accelerating and is drawing a current of 500 A. Tram 1 is drawing a current of 200 A.

Question 1
What is the current in sections P, Q and R of the wire?

Question 2
How much electrical power is tram 2 using?

Question 3
What is the resistance of the overhead wire?

Question 4
What is the voltage at the position of tram 1?

Fig. 1 Question from Victorian Certificate of Education physics written examination 1, June 2003

In our previous review of studies of conceptions and conceptual change in electricity (Mulhall et al. 2001) we concluded that such confusions were contributing to two issues of central significance for the difficulties in learning and teaching electricity that we had identified.

> The current absence of any systematic elaborations of two interrelated issues is of fundamental importance to the teaching and learning of electricity:
>
> (i) what *range* of models/analogies/metaphors are appropriate in the teaching/learning of electricity at different levels of education, including what *justifications* there are for each model etc
>
> (ii) what, in detail, do we expect students to learn when we talk of “conceptual understanding” in electricity, and how might this change with level of education (or, what are *justifiable* forms of concepts such as resistance, potential difference at different levels). (p 583)

Our subsequent work has had the aim of generating such systematic elaborations of models/analogies/metaphors and appropriate learning outcomes for different levels of physics/ science education. In this context, we have undertaken extensive interviews with senior high school physics teachers and textbook authors. Data from these interviews are the focus of this paper.

The interviews were intended to give data relevant to three questions:

1. How are the central concepts of direct current (DC) electricity understood and represented by senior high school physics teachers and textbook authors?
2. What models/ analogies/ metaphors are used for the concepts of DC electricity by teachers and textbook authors, and what justifications do they have for adopting these models etc?
3. What do teachers and textbook authors see to be the nature of conceptions appropriate for learners to achieve at different levels, and what models/ analogies/metaphors do they see as appropriate to use at different levels of education, and with what justification?

The Focus of this Study

We interviewed eight year 11 specialist physics teachers in the Australian state of Victoria, and three authors of year 11 physics textbooks used in this state. The broad focus of the interviews was on the DC electricity section of the prescribed curriculum at this level. In a preceding study of physics teaching and learning we conducted extensive interviewing of physics teachers and students to explore perceptions and knowledge across a range of matters. This experience made it clear to us that in our teacher and author interviews for the present study we needed to consider issues beyond the specific matters indicated in questions 1–3 above. That is, we were aware that in order to be able to interpret better interviewees' responses to questions that asked directly about matters such as understanding of DC electricity concepts, and views about appropriate aims for teaching electricity and models/analogies/metaphors to use in this teaching, we also needed to explore some broader issues associated with interviewees' beliefs about and understandings of physics and physics teaching and learning. Hence our interview schedules included a range of issues beyond understanding, aims, and models/analogies/metaphors, as described below. This led to some interesting, and we believe very important, observations associated with differences between interviewees in views of the difficulty of teaching physics that form the thrust of this paper.

The 'Content Context' of the Study

The specific content of the DC electricity component of year 11 physics in Victoria is of course a significant aspect of the context in which interview responses are given. This is shown in Appendix 1.

There are two important aspects of this content that cannot be seen in Appendix 1. First, the absence of 'electric field' from the prescribed electricity content (which we see as most unfortunate) is *not* an oversight. The evolution over time of this course shows that 'electric field' has been specifically excluded from the DC electricity section of the course. Second, and again evident from evolution of the course over the last decade, there has been for some time a general concern among many year 11 physics teachers that 'voltage' be conceptualized in terms of difference (and indeed for a time there was substantial debate about whether to exclude use of the symbol V in the formal documentation of the prescribed curriculum and use instead ΔV so as to emphasize that *change* is utterly central to the concept.)

The Sample and Approach

As already noted, we interviewed both senior high school physics teachers and authors of senior high school textbooks. As we explain below, we sought two different groups of experienced teachers for interview, one group being teachers whose classroom focus was on student conceptual understanding and the other being teachers with more traditional goals for their teaching (such as solution of standard problem forms).

The Teacher Interview Protocol and Sample

In constructing and then trialing an interview schedule for year 11 physics teachers, we drew heavily on our past experiences in interviewing teachers at this level (noted above). The schedule we developed had a number of sections.

Section A was general – explorations of how the interviewees considered that students learnt physics, and whether or not they saw themselves as "a typical physics teacher."

Section B focused on electricity teaching and learning. First we asked interviewees to consider the section of the year 11 course on electricity in terms of how they saw the difficulty of teaching this section relative to other parts of the course, then we asked if they taught this section differently from other parts, and what teaching approaches they used in this section.

Then we turned to the content of the course. We asked them how they would expect their students, after completing this section of the course, to answer a number of questions relating to a DC circuit containing a cell, switch and one (or two) light globe(s). This circuit was then used to probe the understandings of the interviewees themselves of the concepts voltage, potential difference, voltage drop, EMF and electric energy.

Section C asked about "models and analogies" – the meanings the interviewees had for these terms, their view of the value of these for students learning electricity in year 11, and any differences in useful models and analogies at different levels of teaching electricity.

A final question explored views of the importance of teaching about the nature of physics.

The complete interview schedule for teachers is in Appendix 2.

Each interview took of the order of one hour, and each was undertaken at a place of convenience to the teacher (in all but one case at their school). Mostly, there were no difficulties in the conduct of the interviews. However the very demanding nature of some of the interview questions did raise potential problems in a number of cases. As we describe below, some interviewees found that, as the interview progressed, their perceptions of their own understanding of these electricity concepts changed – and the change, when this occurred, was always towards growing recognition of significant inadequacies in their own conceptual understanding that they did not realize at the start of the interview. These occurrences needed handling with considerable care and tact.

Because of the purposes of the research project, we sought experienced teachers for this interview. In previous physics education research, noted briefly above, we studied classrooms and consequences both in classes where teachers focused on conceptual understanding and in classes where teachers focused on more traditional problem solution outcomes. The insights from this work included the data-based observation of generally greater conceptual understanding among the conceptually focused teachers. This made it clear to us that we should seek to include in the present study some teachers whose focus was on student conceptual understanding.

Hence we sought two different groups of experienced teachers for interview. One group (of 3) were teachers whom we knew focused strongly in their physics teaching on student understanding of concepts (these teachers we describe as 'conceptual', and identify below as USG1, USG2, and USG3). The second group (of 5) were teachers whom we did not know as well, but had reason to believe did not focus as strongly on student conceptual understanding (these teachers we describe as 'traditional;' and identify below as TRAD1 to TRAD5). One of the 'traditional' group had only been teaching for 18 months, the others had extensive physics teaching experience. For ethical reasons (maintaining complete anonymity) we do not identify which of TRAD1 to TRAD5 is the less experienced teacher.

The Author Interview Protocol and Sample

We also sought to interview authors of textbooks commonly used in year 11 physics classrooms in Victoria. The interview protocol we generated was similar to that for the year 11 classroom teachers, but not identical. These interviews were intended to be more extensive than the teacher interviews, and so the protocol was planned to be in two parts to correspond with two interview sessions with each author. In this structure we had all questions relating to conceptual understanding of electricity (students and interviewees) in the second part. The outline of the protocol that now follows indicates the two parts.

Part l Section A began with the same general question (from Section A teacher interview) about how the interviewee considered that students learnt physics, but the remainder of this section focused on them as textbook writers (perceptions of place of texts in learning, how they saw their 'typicalness' – or otherwise – as a textbook writer, their rationale for the general structure of their textbook, and the place of the nature of physics in their textbook).

Part 1 Section B asked about the section of their textbook that related to the DC electricity component of year 11 physics (perceptions of ease/ difficulty of writing, perceptions of concepts difficult to 'convey', and how the section would now be changed if the book was rewritten).

Part 1 Section C asked about models and analogies, and was identical to Section C of the teacher interview.

Part 2 Section A was very similar to the part of Section B of the teacher interview that focussed on concepts of electricity. We asked authors how they would expect students, after completing this section of the course using their textbook, to answer a number of questions relating to a DC circuit containing a cell, switch and one (or two) light globe(s). This circuit was then used to probe the understandings of the interviewees themselves of the concepts voltage, potential difference, voltage drop, EMF and electric energy.

Part 2 Section B then asked about specific matters in the electricity section of their textbook that we had identified through detailed prior analysis of their text (ways analogies were used in the text, ways problems were used in the text, and so on).

Part 2 Section C involved giving some student statements about electricity to the interviewees and asking them to consider what the statement revealed about the understanding of the student who made it. The intention of this section was to explore the understanding of the author in a different way.

The complete interview schedule for authors is in Appendix 3.

Each *part* of the interview took an hour or more (that is a total interview time of two to three hours). One author chose to have both parts together. Each interview was conducted at the workplace of the author (their choice). The only difficulties in the conduct of the interviews were as for other teachers – the demanding nature of questions concerned with exploring the author's conceptual understanding did lead to some self-questioning about understanding. Again these situations needed very careful handling.

We interviewed three authors (identified below as AUT1 to AUT3). All had extensive experience in teaching high school physics. Two of the authors were currently teaching high school physics, and the third had very recently left the classroom but was still working in an educational context. There were times in all three interviews when the interviewee responded more as a teacher than an author. AUT 2 did this least, and AUT3 responded as a teacher to almost all questions (and was explicit about this on a number of occasions).

All three of us conducted interviews, and each transcribed the interviews we had conducted and generated brief summaries of the issues we saw as interesting and relevant. As interviews were completed we collectively discussed transcripts and reconsidered the summaries.

Data and Discussion

There are a number of themes in the data that are relevant to physics teachers' perceptions of the difficulty of teaching electricity. We present summaries of the data under these themes, and give illustrations via selected extracts from the interview transcripts. The first two of these themes are obvious – teacher views of how students learn physics, and responses to direct questions about perceptions of difficulty of teaching electricity. Then we consider other relevant themes. We discuss in detail the understandings of interviewees of some concepts central to DC electricity, and then, very briefly, aspects of their views of the related two issues of models/analogies and the nature of physics.

Views of How Students Learn Physics

There was some validation of the categorization of our interviewees into two groups. For example, all the three teachers we categorized as concerned with understanding (USG1 to USG3) gave responses consistent with seeing learning in terms of student conceptual understanding, although USG3 gave these perspectives much more from a teaching position than a learning position. We give some extracts from each of these three interviews.

> It comes back to your fundamental views of how people learn anything…the old constructivist view, you construct the meaning for yourself of what's around you, filtered through your view of what the world is and what your experiences have been before. The big challenge in the physics of course is that what seems obvious in the experience of the world is actually not what really happens…So the kids have got to construct their own understandings of all this sort of stuff and my views **have** (*his/her verbal emphasis*) changed in more recent times, because we are involved with this thinking-oriented curriculum stuff, which is more general views about how kids learn, and what's good learning and powerful learning. (USG1)

> The process they need to engage in [in] order to learn it, is to think about it and try things and ask questions and hold conversations…generate questions of their own which are amenable to some form of modelling that involves an experimental check if at all possible. And then while they are doing that you can get around and talk about what's really going on…the classrooms where my guts told me there's a lot of learning going on are classrooms where there's a buzz, and the buzz is argument and discussion and actually trying it. (USG2)

> A lot of the time I try and get them to model things and actually do things. Like with forces, you know, push them and pull them and they can see things happening with tennis balls or with people or whatever and that's much harder with electricity so it tends

> to be mainly analogies and things that we use when I try and teach it to the [students] so…we do practical work and measure voltage and current and things like that. But then explaining why you're getting those readings – there's nothing you can actually sort of show them. You've got to then go to an analogy or some sort of explanation that's more theoretical to try and explain why they're getting those readings and things. (USG3)

Only one other interviewee (AUT2) answered this question about how they believed students learn in terms of learning alone. There were very different positions taken by some of the other teachers, and some talked *only* of teaching (a position that we argue is clearly indicating a view of learning that is inherently transmissive – learning is seen solely in terms of what the teacher transmits).

> Mostly they learn it by relating to something that they know. Students seem to find it much easier to learn if you can give them a concrete example. They don't like sort of things that don't make sense. (Pause) Being in a [single gender] school they like to learn by hands on. We try to do a lot of practical work here. They don't like to sit still and take notes. It's a bit of a battle at the moment but in general they would prefer to…have some input into what they're learning, whether it be answering questions or doing some sort of practical work. It all needs to have something they can tie it back to – something within their own understanding of the world that they can tie what they've learnt back to. (TRAD1)

> The best way for them to learn is if examples can be used that they can somehow relate to. Sometimes that's a bit difficult when the concepts…are a bit more abstract. I certainly do quite a lot of practical work so the students are discovering the behaviours and patterns for themselves [rather] than just listening to me tell them about it or demonstrat[ing] to them…the prac work's structured so there's questions that guide them to where I want them to go. That's the way I find they best learn. (TRAD3)

> I always start off from [real life situations and contexts] point of view because I think it's something that the students can relate better to. So you start off by, um, things that they're familiar with and then use those to build your concepts and construct your topic development out of. So that's a point of view that I hope I usually start off from and that's reflected in the textbooks and that that I do. (AUT3)

The concern with real life examples and the significance of relating what is to be learned to these examples was a common feature of the interviews here. This is consistent with one general philosophy underpinning the Victorian year 11 physics course for well over a decade (an emphasis of some sort on contexts), and is also consistent with the findings from an earlier study of the views of quality learning of senior high school physics teachers and university lecturers in Victoria (Brass et al. 2003). There was, surprisingly, relatively less mention of practical work; the quotes above from USG3, TRAD1 and TRAD3 are all of the substantive practical work references. These three quotes emphasize significant differences in the ways student learning is central or not to the ways the teacher understands and uses the student laboratory. The one understanding teacher (USG3) is clear in his/her recognition of the difficulties of laboratory work in this conceptual area (all observations are indirect representations of concepts/ phenomena, there are major leaps needed to get from these indirect observations of concepts and relationships, etc.). On the other hand, both the traditional teachers (TRAD1 and TRAD3) explicitly note their view of some form of direct and linear (and apparently teacher independent) path from observation to learning – a clearly naïve view.

Views of the Difficulty of Teaching Electricity at Year 11

We found a range of views among the teachers here, a finding that surprised us. All three ‘understanding’ teachers made quite strong comments about the difficulties of the concepts, including (but not only) the forms of difficulty that arose from the abstract nature of all these concepts. One of these teachers (USG1), who described the concepts as “whoppers” in advancing the position of difficulty in teaching electricity at this level, also indicated the range of available and relevant “simple experiments” as a plus for teaching here because it enabled the teacher to provide a range of observations/explorations of relevant phenomena.

The ‘traditional’ teacher group presented a more varied general picture, although generally they saw the teaching of electricity as less difficult than the ‘understanding’ teachers. For example:

> I think **here** [at this school; interviewee’s verbal emphasis] that the students are more interested in electricity…than other sections, [because] they actually make up their own circuit at the end…so they get that hands on thing and they really like it…it’s the last thing we do and the students really look forward to doing it….In terms of the basics of electricity, they [the students] seem to understand it. (TRAD1)

> Probably is one of the more difficult areas….Some of the concepts in motion the students have difficulty [with] but on the whole a lot of the motion stuff they perceive as difficult to start with because they’ve never seen anything like that before, i.e. vectors…but once they get started…and start working on problems they get the hang of [them] and find [they’re] not too difficult. But with electricity … they struggle with the concepts for a lot longer I find. (TRAD3)

> It would sit in between some of the others.…the simple DC circuits I find generally speaking at the easier end of the spectrum [of electricity topics] (TRAD4)

The other two ‘experienced’ teachers gave responses that we believe are not reasonable.

> I don’t think teaching it is difficult, mainly because [of past work experience]. Sometimes the concepts for the students to understand is probably difficult, but I don’t think teaching [is]. (TRAD2)

> The actual teaching of it I don’t think is terribly complex. I don’t think there’s enough time allowed in terms of the breakdown of the course to do it really well. But what I’ve found is the kids don’t develop a deep understanding of electricity. (TRAD5)

We confess to having considerable difficulty with the notion that teaching can be easy when it is recognised that learning is difficult.

The three authors (who were asked about difficulty, in comparison with other areas, of writing the electricity section) also varied, but in different ways. AUT1 saw this section as harder to write because of the difficulty of the concepts, AUT2 saw this as easier to write because he/she had to do less research for the writing, and AUT3, who responded in terms of concept and content difficulty in this section of the course, saw it as no different to other sections.

Understandings of Electrical Concepts Held by the Interviewees

We consider here understandings held by the interviewees of the concept ‘voltage’ (and when relevant ‘potential difference’ and ‘EMF’). We focus on these specifics because of the rather disturbing aspects of understanding that are revealed by the interviews.

Some of the responses to our questions relevant to the interviewees' understandings of voltage and related concepts were clearly inadequate. In this case quite extended extracts are needed to give even some brief sense of responses.

TRAD1: [A few starts in trying to frame a response, with comments that he/she always has to check on these terms him/herself and hopes he/she is not confusing students.] Voltage is the energy available to the circuit or energy used by the circuit. You have voltage drop. Voltage as a concept, I guess, is difficult. I found myself talking in terms of potential drop last year to explain [that] there were different potentials within the circuit and that potential drop varied depending on what the circuit elements were.

[Later](Whispers) How can I explain voltage? (Then aloud). I'm going for voltage is how much energy is available to the circuit usually from a stored source. A potential drop, so I'm talking potential difference – and I like to work from potential into voltage – potential drop is the amount of energy– this is very simple – used…by a resistance or some circuit element that uses energy.

I: So potential drop is different to voltage.

TRAD1: Sort of, yeah. I guess potential drop's outside of the – I'm thinking voltage [is] in the battery and that's not right either …

TRAD2: I would approach it in terms of potential. So I would say voltage is potential and I would always equate it to the fact that comparing it to a hydroelectric scheme. [Then elaboration of this gravitational potential energy analogy] I would say there is a difference in potential or a difference in energy levels between one side of the component and the other and the fact that rather than say "What is a voltage?' I would interpret it as a change in potential, a voltage drop or a potential drop if you like rather than explain what voltage is, and I would try to explain it in terms that the energy is lost as the charges move from one point in the circuit to another. So there a change in potential between two points in the circuit.

I: Using the same circuit could you explain to me what you mean by 'emf'?

TRAD2: I try to get across to the students that it's the energy given to the charges to drive them around the circuit. Quite obviously emf is electromotive force. So it's the driving force if you like which propels the charges around the circuit.

TRAD4: Voltage would be the amount of energy that each of the particles carries with it, so it's got nothing to do with its particular speed. So I like to get it into a sort of particle definition to simplify things. [Explains an analogy he/she uses in teaching] So my definition of voltage would be the amount of energy each of these particles, not really particles, but each of these packets is carrying.

I: What do you think about the use of the terms voltage, potential difference and voltage drop?

TRAD4: Shocking.

I: For you do they mean the same thing?

TRAD4: (Pause) Effectively, except I would use 'voltage drop' in … one of the components rather than in the cell, so as to where it fits in a particular circuit. … I would use 'voltage drop' across the globe.

I: Where would you use the various terms?

TRAD4: I tend to use them for the same thing. So ‘voltage drop’ I would use across parts of the circuit, except the cell. ‘Potential difference’ I would use specifically for the cell. … And even just the word ‘voltage’ across the globes as well. So I would mix up ‘voltage drop’ and ‘voltage’. I tend to avoid using [potential difference] except for the cell.

I: How would you use it for the cell?

TRAD4: (After some umming and ahrring) I would say officially the ‘potential difference’ is commonly referred to as ‘voltage’, but the ‘potential difference’ term comes from the fact that the energy they left with [from the cell] and the energy they returned with is different….The ‘voltage drop’ is another type of potential difference but I wouldn’t use it there [across a component], ‘voltage drop’ implying that it gives off its packets of energy at different parts around the circuit.

I: Do you see the terms ‘voltage’ and ‘voltage drop’ as two different things?

TRAD4: Um. (Pause) No.

I: Before you were saying the ‘voltage’ is the amount of energy this little unit has and ‘voltage drop’ is how much it loses. …Do you see them as different or not?

TRAD4: Yes. Technically I see them as different….I would use ‘voltage drop’ to imply that the energy was being used. That’s when I would use ‘voltage drop’. I would use the ‘voltage across’ and ‘voltage drop’ in the same sort of way. I would generally use the word ‘voltage across’. I don’t know whether that’s right or wrong but that’s what I would use.

I: With the same circuit…

TRAD4: (cutting in): You’re going to bring in emf next, aren’t you?

I: Yes (We both laugh)

TRAD4: That’s what I was afraid of.

I: Using the same circuit could you explain to me what you mean by ‘emf’?

TRAD4: (After some umming and ahrring) No, emf I just refer to. It’s the electromotive force. It’s terminology and I just leave it there. And I say that’s the official ideal voltage of that cell. And we’ve got this fancy E [the symbol for e.m.f. that the interviewee used]. That’s it.

TRAD5: Oh! That’s not fair! (Both I and TRAD5 laugh.) I need my textbook. Where’s my textbook? (Pause) …. I’m going to stuff this up totally. I always do stuff up voltage. (Pause) I can’t even think of what the definition of voltage is. This is disgraceful.

I: No, it’s not. Believe me there is an enormous divergence in what people understand by voltage.

TRAD5: Voltage is the potential of the cell. It is the energy stored in the battery to drive the electrons through the circuit.

I: So that would be the voltage at any particular spot on this circuit?

TRAD5: Yes, the number of charges per (pause).

[Extended section of transcript not reproduced here]

Voltage and potential difference at the battery is the difference from one side of the terminal to the other.

I: The difference of?

TRAD5: Of, uhm (long pause) basically the different energy levels of the battery. So across here (pointing to the two terminals of the cell in the diagram) you've got a voltage drop but you've also got a potential difference because one side is higher than the other. So yeah, I'd say they [voltage drop and potential difference] are the same.

I: How about the term voltage?

TRAD5: If I say that a battery is 12 volts, then what I'm saying is that from one side to the other there is a drop in voltage of 12 volts. So if I'm talking about a voltage, I'm talking about a voltage drop.

I: Using the same circuit could you explain to me what you mean by 'emf'?

TRAD5: Electromotive force. In terms of my terminology I've always said it's either voltage or electromotive force, and electromotive force is basically the energy to drive the electrons around the circuit. But I know that's not correct. (Laughs). I mean some textbooks have emf and some have voltage for the batteries. So I always say … in Year 11 they tend to talk about voltage more than emf and yet when you get into Year 12 textbooks they talk about emf and the kids go 'Oh, what's emf?' Then I just say basically it's the voltage of your battery.

I: So the voltage of the battery and the emf of the battery are the same thing?

TRAD5: Yes. Am I going to get sacked? (Both laugh)

These quite extended extracts from four of the five 'experienced' group make clear a number of things. Our explorations of understandings were quite detailed and probing. Perhaps because of this, a number of the interviewees were very uncertain of their own understandings of voltage/ potential/EMF, a number went through changes of ideas as they thought about questions, and a number were extremely uncomfortable about this content. We find it particularly interesting, for reasons noted in the conclusion, that TRAD2 and TRAD5 (who each indicated at the beginning of their interview that electricity was relatively easy to teach but that students found it hard to learn) both reconsidered this teaching position during the interview. It was clear in both cases that this reconsideration of ease of teaching resulted from a growing awareness of their own conceptual inadequacies.

The understandings of USG1 and USG2 would require even longer extracts to be represented adequately. One feature of these two is that, while recognising the same general uncertainties as are evident in the TRAD quotes above, it was clear that USG1 and USG2 had given considerable thought to the meanings of these components as part of their approaches to teaching them (that is, long before the interview). While the interview also produced moments of discomfort for them as well, the discomfort did not come from not having thought about the concepts in this way before. Rather the discomfort came from existing recognition of the complexities in these concepts. USG3, on the other hand, showed the same broad uncertainty as was evident in the transcript exerts above from some of the 'traditional' (TRAD) group.

I: From what you've said [earlier in the interview] voltage is the energy given to each charge by the battery, is that right?

USG3: Yeah, I don't sort of get into. (Breaks off) Yeah.

I: And then you go actually go and have a look at definitions in the textbook…?

USG3: We (never?, recording unclear) use the formula to, you know, work equals QV so it's actually a coulomb of charge, we're talking about not one electron for the amount of voltage, but it's still to do with the energy given to the charges so yeah we then go to that step.

I: Do you use the [expression] potential difference at all?

USG3: Yes, most of the time and I'll say to [the students] that [in] some textbooks they'll see the word voltage, sometimes they'll see potential difference, and I explain to them that as it goes through it might have this voltage of 6 volts here when it goes through and if it's 2 globes [and] a 6 volt battery, they say lose 3 volts there so what there is a potential difference across there of … 3 volts …. So they sort of start to know that [voltage and potential difference are] similar terms and I don't go into any sort of detail of any differences between them. But they've seen and understand a bit about both the words.

I: So what do you see as the difference between them?

USG3: (Loud embarrassed? sigh) Um. (Pause) I'm not sure I can answer that properly. I haven't looked at that for a couple of years. I know there is a difference but off the top of my head I can't remember exactly what it is, but I know they're not the same thing. I say that to the [students] but because I don't have to go that far, I can't remember myself now.' (Small laugh) That's why I hate these interviews! You make me (unintelligible word) things I don't know! (Still laughing)

I: And voltage drop, do you use that [expression] too?

USG3: Not really, I use just voltage and potential difference …

[Further brief discussion reiterated that he/she tells the students voltage and potential difference can be regarded as the same thing…. he/she saw voltage and potential difference as being slightly different (but could not say how), for all practical purposes they were the same and she told the students that in problems they meant the same. He/she did not use the expression 'voltage drop'.]

I: Using the same circuit could you explain to me what you mean by 'emf'?

USG3: I tend not to use that [expression] much at year 11 because, um, I find that with the word force in it, it just confuses them when they've got enough misconceptions, so we talk about that a bit at year 12 and I often just give them the definition but I tend not to go very far down that path. Um, again the textbooks often interchange those three words a bit anyway so it's often mentioned I say to them "Just don't worry about that one. It's another one like voltage. Those things all sort of mean similar sort of things but I tend not to use [emf] with year 11's unless they come across it in a textbook and then I'll sort of explain it.

I: So what does it mean to you?

USG3: It's to do with the, um, energy potential of the battery itself, um, I s'pose (sighs) is how I think of it.

[Did not pursue further as USG3 was obviously somewhat uncomfortable with questions about the meanings of voltage, potential difference and emf.]

AUT1 and AUT2 had less uncertainty about their answers to the voltage questions, and showed understandings that we see as more acceptable than some of the above. AUT3 however was uncertain.

AUT3: Um, I see voltage as being – I stress this word there – an **indication** (interviewee's verbal emphasis) of the energy that the charges have got, um, and ah, so, you know, you can talk about the voltage that the battery has got there and the voltage that, ah, is used up by the globe so, um, I always, you know, explain it in that way, that it's an indication [of] the energy that the charges have got flowing around the circuit.

I: What about potential difference, do you see that as being different to voltage?

AUT3: Um there's three terms that often get mixed up and you see them used in different ways in books and that. Potential difference is one, voltage is the other, and emf is the other – those three things. Emf and potential difference are sort of the old traditional ones there and we tend to use voltage as being more familiar to students cos they can relate better to that than the other two terms. Um, at the senior level there, um I make use of and mention all three there. And I talk about or explain potential difference, ah, from the point of view of, if you look at the light globe [that's] glowing there: um on one side of the globe there you've got the charges come in with a certain amount of energy, or electric potential energy if you like, and on the other side they emerge with less electrical potential energy and therefore you can look at the globe as on one side you've got more energy and on the other side you've got less and therefore there's that difference in energy that the charges have got and I …refer to that as that's the potential difference or electrical potential difference. Um, if we put a voltmeter across that globe there then the globe (sic) is really measuring the difference in electrical potential energy from one side to the other and it does a little subtraction and gives a reading.

I: And is the electrical potential difference what you see as being voltage?

AUT3: And I say we often call that, or just refer to it commonly as voltage, yeah. Um, emf is mainly the term used for, um, the voltage across a battery there with no load on it. Um, when you put a load on there, the voltage drops a little bit. Um, so, you know, the emf has a little bit more precise meaning there, um. I use emf as being the voltage across a battery there with no load: when you put a load on, the voltage drops down a little bit and then you tie in things like internal resistance of the battery and things like that.

….

I: So voltage is not potential difference to you?

AUT3: (Speaking slowly) They're…fairly similar. (Speaking faster) I tend to use them in a fairly similar way. Cos I tell students that…we use the term emf and we've got potential difference there and voltage and I tend to tell them that you know, really all those things are sort of voltage if you want to use one sort of term, um, even though you know scientifically each of them on their own [has] got a more precise meaning, um, but I still um prefer to use the word voltage to refer to any of them or all of them.

In summary, then, there are a number of teachers and one author for whom we believe the most generous assessment of their concepts of voltage etc is that these are vague and uncertain.

Views of Models and Analogies

Just as the probing of understandings of concepts revealed uncertainties and inadequacies in the ideas of some interviewees, so did our questions about models and analogies. In particular, some (USG3, TRAD1, TRAD2, AUT1) implied or even directly stated that models were necessarily physical realities (as in "model car"), and some (TRAD4 and AUT3) did not (and we believe could not) differentiate between models and analogies. We see this an indication of inadequate understanding of central aspects of the nature of physics knowledge every bit as concerning as the conceptual understandings above, and illustrate this with extracts from the responses of two of the interviewed authors to questions about what they meant by the terms 'models' and 'analogies'.

> A model is a, um, probably a replica of something that is used in practice. For example you can build a model of an engine, to me that would be almost a scaled down version of a real motor or something that they've [students] pulled apart, they've redrawn, something more concrete. Whereas an analogy to me I would see as a little bit more abstract and I would use the analogy of water flowing around the house, through the pipes, the taps, the pumps, as an analogy as to what the electricity was doing around a circuit in terms of carrying energy and so on. (AUT1)

> Um [unintelligible words] difficult ones to define there. Yeah, um, ah … Both of them are sort of tied in there um I s'pose…you're trying to use a simple little situation to, ah, help you explain a more complicated concept. Um, and your simplified, um, model there is, um, trying to represent abstract things that are in your concepts, um, and… they're all geared around trying you know to help students to understand something that they can't really see all that well. For example you can't, um, you know magnify a piece of wire and actually see electrons flowing through it so in using a model there, an analogy you're trying to get students to picture in some way something that'll help them to understand. For example the model of the train coming around, so they can sort of picture what happens to a train and then…try and relate that to what's going on inside the wire. And analogies is a bit um harder to um define there. I don't see them as being a great deal different there. I sort of use the two of them in that way that I've described…I suppose they're tied in with, you know, giving the student an example of something that's similar to, you know, an abstract idea that you're trying to get across. Um, I probably haven't explained both of those two things all that well but probably…I don't often see the requirement to sit down and define those things. [Laughs] (AUT3)

The two teachers from the Understanding group not yet referred to in this section (USG1 and USG2) both gave insightful and comprehensive responses in this section of the interview. For example:

> What I tell my students a model is, and they get the definition in a joking sort of a way quite early in the piece, and then we…tease it out…"Reality is too difficult – let's just pretend…" which they laugh at and they think it's funny but I think it's actually really a deep truth [speaking slowly] in the sense that reality **is** very difficult and [in science] we are about making approximations to it. And so we say "How about we think about it this way - how fruitful is this? And when that doesn't work – how about we think about it this way, how fruitful is that?" And I believe there is something called reality that science is constantly approximating, but I actually **don't** believe that any of the things

> science has to say about reality are any better than models. And some of the models are very, very powerful and you can run your life on those models quite confidently. But they're still models so the mathematics is a model, and the role play is a model, and… every explanation we give is modelling. And there are some things…when I think of quantum mechanics, I get really frustrated because I can do the mathematical modelling but I haven't got **words** to describe the results that come out of it and I feel a bit that way for the behaviour of electrons in wires in a circuit…And every time I think I've got a good explanation the electrical engineers tell me I'm wrong – they've got a better one…I mean – holes, PN junctions, electronics – stretches everything.
>
> Analogy is different from a model…they're alike in some ways but I think…with a model there is always a possibility that you can kid yourself that that it **is** reality whereas with an analogy you always know it's not. So nobody, I hope, really believes that charges are like people walking around with "M and Ms" – that really is an analogy…that is the analogy you would use to teach a transport model… (USG2; verbal emphases in original)

Views of the Nature of Physics

We chose not to ask directly about how interviewees saw the nature of science/physics, but rather to ask how important the interviewees saw it that students "learn about the nature of physics" (for both TRAD and USG teachers; see Appendix 1, Qn 13) or "learn about the nature of science from a textbook like yours" (authors; see Appendix 2, Qn 6). Interviewees' responses sometimes made explicit their own views of the nature of physics, and sometimes we could only infer these. Within that limitation, it was clear that only USG1 and USG2 articulated cohesive views that they had obviously given substantial thought to before (and thus quite independent of) the interview experience. Both these teachers had views that were consistent with their positions on the nature of models and analogies. For example, when teacher USG2 replied to our initial question that it was very important that students learn about the nature of physics, he/she was asked why it was important. He/she responded

> [whisper] Because that's the most exciting bit of it….The whole idea that humans have actually had the audacity [breaks off]…[Normal voice] There's also the aspect that if you don't understand that very **deep** idea about science which is that it has certainty **and** uncertainty built into its very foundations then the nature of scientific knowledge – you're either going to believe the experts far more than is good for either you or them or you are going to devalue the experts because they allow themselves to be uncertain, and either of those [positions], given the place of science in our society, is…very dangerous… (USG2; verbal emphases in original)

A number of other interviewees, including AUT3 found this section of the interview very difficult, and in some cases it took several questions by the interviewer before even an understanding of the question was established.

Conclusion

There is surprising (to us) variation in perceptions of these interviewees of the difficulty of teaching electricity at this senior high school level. Of particular concern is that some teachers saw this area as easy to teach even though they also saw it as hard for students to learn.

There is some weak linkage between the extent to which interviewees understood the concepts themselves and their views of (1) learning of physics (and thus electricity), and (2) difficulty of teaching electricity. Teachers with more informed and elaborated views of learning tended to have better understandings of the concepts of DC electricity and to have a more informed sense of the difficulty of teaching in this area. Teachers who saw this area as not at all difficult to teach tended to have simple (we would argue generally simplistic) views of learning and understanding of concepts.

The levels of conceptual understanding of the concepts of DC electricity of some teachers and one author are of particular concern. This is further emphasised by consideration of what was not mentioned as well as what was said in response to our probings of understanding of voltage, potential, EMF etc. In their responses to our questions interviewees very rarely considered energy *sources*. And there was not a single instance of consideration of why energy sources in electric circuits have 'joule/coulomb' and not 'joule' as a descriptor. We regard this as indicating inadequacies in understanding. Some of the views advanced about models and analogies only serve to reinforce these concerns, particularly given that two of the three interviewed authors had less than helpful views of what models and analogies were. This summary of our inferences about interviewees' views of the nature of physics presents a picture that is quite consistent with their views of models and analogies. This gives even more reinforcement to our fundamental concerns about the nature of conceptual understanding of electricity held by a majority of these teachers and authors.

The author data presented above have been considered here in the context of these authors as experienced physics teachers. These data are of course also relevant to their textbook writing and raise obvious questions about their textbooks and the treatment there of these concepts and use of models/analogies. We have considered the three authors, their understandings and their textbooks elsewhere (Gunstone et al. 2005).

There are some consistencies between these data and other studies of teacher understanding of electricity (of middle school science teachers in Pakistan, Pardhan and Bano 2001; of engineers teaching first year college physics in the Philippines, Tabanera 1995). However the extent of probing in the interview approach used in the present study reveals inadequacies among teachers who would have likely appeared to understand well (or at least not as poorly) if the pencil-and-paper instruments used in these other studies had been used here.

We see one obvious conclusion to draw from this demonstration of conceptual inadequacies and epistemological uncertainties (for concepts and models/analogies and nature of physics). We see this as most likely to be the consequence of inadequacies in the content and quality of undergraduate physics teaching. For example, an inspection of undergraduate physics programs reveals little or no attention to *concepts* such as voltage, potential difference and emf; the focus is on more complex mathematical representations (certainly one aspect of enhanced understanding, but only one aspect) and the solution of more and more complex problems. There is, for at least most of the contexts for which we have some awareness, very little concern with the understanding of these fundamental concepts brought to undergraduate physics by high school graduates being further developed in undergraduate programs. There is a strong if indirect reinforcement of this problem in our finding two teachers (TRAD2 and TRAD5) for whom it was clear that the experience of this interview resulted in them reflecting on the nature of some concepts (in particular voltage) for the first time. Reflection on the nature of complex and abstract concepts seems a very reasonable expectation for undergraduate study, an expectation we believe was not met for either of these teachers.

This of course raises the issue of the ways university physics academics understand these concepts themselves. Early in this paper we briefly referred to the conceptual and pedagogical confusions we had previously noted among teachers and in textbooks (Mulhall et al. 2001). We gave as a particular example of these confusions a question from a recent final year high school physics examination (see Fig. 1 above). We repeat here that the panel of experts responsible for writing this question included a number of academic physicists. This and other data, such as conceptual inadequacies in the electricity sections of undergraduate physics textbooks and the arguments in the previous paragraph, lead us to the position that the conceptual understanding of electricity of academic physicists may well also exhibit forms of confusions and inconsistencies. Our next step in this research project as a whole is then, not surprisingly, to seek to interview academic physicists who teach undergraduate electricity, with an interview schedule that probes the same issues as those used in the study reported here.

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Appendix 1: Outline of electricity section of Physics curriculum in Victoria at the time of interviewing

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Year 11 Physics Unit 2 Movement and Electricity

…

2. Electricity

Central Ideas

The use of electricity underpins much of the structure of our lives. Safe and effective use of electricity is important for individuals and the community generally. Much of our present use can be explained by basic DC circuit theory.

The area of study should include:

- current, charge, voltage, energy and power in series and parallel circuits (including $Q=It$, $W=VIt$, $P=VI$);
- Ohm's law and resistance in series and parallel circuits (V-I graphs for ohmic conductors; $R_T=R_1+R_2$ and $1/R_T=1/R_1+1/R_2$);
- non-ohmic devices (awareness of their existence; examples of some V-I graphs);
- cells, batteries and power supplies (including EMF and internal resistance); and
- electric shocks

(descriptive treatment of effects on humans, awareness of approximate quantities at danger thresholds)

These ideas should be used to explore **one** of the contexts below.

Contexts

Household use of electricity

(for example, measurement of electrical energy consumption; power ratings; fuses; switches; correct wiring including the role of the earth wire; double insulation; torches; walkmans; batteries; cells; safe practice.)

or

Car electrical systems

(for example, wiring diagrams; earthing through the car body; battery charging and discharging; door switches to interior lights; dimming of headlights while starting; jump starting a car; safe practice.)

or

Electricity in isolated locations

(for example, solar electric cells and their efficiency, 12 V operation, power ratings; switches; comparison of solar electrical systems with diesel generators; safe practice.)

Appendix 2: Interview schedule used with year 11 physics teachers

Preamble:

"We are interested in your ideas about the teaching and learning of DC circuits, and the use of analogies and models in helping to develop students' understanding of electricity ideas."

A. General

1. How do you consider that students learn physics?
2. Do you see yourself as a typical physics teacher?

If "no": Why not? How do you see yourself as different from other physics teachers?
If "yes": What do you think you have in common with other physics teachers?

B. For the remaining questions I want you to consider the section of the physics course relating specifically to **electricity**

3. In comparison with other sections of the course how would you rate the difficulty of teaching this section (electricity)? Do you try to teach in this section in different ways to other sections of the course?

(If not clear from response ask "Do you find any concepts in this section of the course difficult to teach?"
[If *Yes*] "Which one(s), and why?")

4. You have talked about things that are different in your teaching of electricity. What other things do you do when you teach electricity?

(Explore use of quantitative problems, web-based material and prac work in particular.)

5. (Show card with circuit containing a cell and a resistor/globe and a switch) *(symbolic)*

(a) After you have taught the electricity section of the physics course, how would you expect students to explain, when you close the switch

– why the globe lights up?
– why there is a current in the globe?
What aspects of your teaching would assist students in achieving this understanding?

(b) Is this an understanding that a scientist would agree with?
(c) What is the evidence/basis for the scientific explanation?
(d) Do you consider it necessary to provide students at this level with this evidence? (Trying to get at statements like "if XX conducts it must contain charged particles")
(e) Think about students at years 7, 10, 12: what differences in student understanding of this circuit would you expect at each of these different levels?
(f) What do *you* consider to be the fundamental concepts for understanding a simple DC circuit such as this one [the one on the card for Qn 5]?
(g) We [the researchers] have often been asked by students over the years about the effect on this circuit of adding a light globe–

in particular, if a second globe is added after the one there now *(draw this on circuit)* how does the first light globe 'know' that there are now two globes involved, and that there is now a lower circuit current.
If one of your students asked this, what response/explanation would you give?
[Qns 6–8 may have been answered in various sections of Qn 5 - lots of "playing by ear" assumed!! Reference to the circuit for Qn 5 is assumed for Qns 6–8.]

6. Using the same circuit could you explain to me what you mean by 'voltage'?

   [If *potential difference* and *voltage drop* are not mentioned]
   What do you think about the use of these three terms? For you do they mean the same thing?

7. Using the same circuit could you explain to me what you mean by 'emf'?
8. Using the same circuit could you explain to me what you mean by 'electric energy'? (What has it and where is it?)
9. Imagine we have a circuit with a cell and two resistors in series, as on this circuit diagram (*show diagram*) and we ask this question: "If the resistance of one of the resistors is increased, what happens to the current in the other resistor?" How would you expect your students to approach answering this question?

C. One of the things that teachers often discuss when they are talking about teaching electricity is models and analogies.

10. What do you mean when you use the terms models and analogies?
11. Do you think that models or analogies are helpful or unhelpful for students at this level learning about electric circuits?

    [If *Unhelpful*] Why?
    [If *Helpful*] Which model or analogy? How is it helpful?

12. [IF "*Helpful*" is response to Qn 11] Think about students at years 7, 10, 12:

    Do you think there are any differences in the sorts of models and analogies that are helpful for students at these different levels?
    [IF "*Unhelpful*" is response to Qn 11] Think about students at years 7, 10, 12:
    Do you think models and analogies would be helpful at these other year levels?

13. How important do you think it is for students to learn about the nature of physics?

    (alternative approaches if needed: "the way physics develops", "what is physics?"…)
    If "is important" then "how do you make it part of your teaching?"
    If "NOT important" then "given that this is often included in physics textbooks, why not?

Appendix 3: Interview schedule used with authors of year 11 physics textbooks

(NOTE: The actual form of schedule used for each of the 3 authors interviewed contains specific references to the book they had authored that would enable identification of the author. Therefore all such references have been removed from this form of the protocol.)

Prior to interview make clear to X that subject of interview includes in part electricity section of book written by X.

Part 1 (of 2 part schedule)

A. General

1. How do you consider that students learn physics/science?
2. What do you think is the place of a textbook in student learning, at this senior physics level?
3. What were your main purposes for writing this book?
4. Do you see yourself as a typical physics textbook author?

   If "no": Why not? How do you see yourself as different from your competing authors?

If "yes": What do you think you have in common with other authors?

5. If a group of Year 11 students was asked "In what ways is this book helpful to you?", what do you **hope** they would say? what do you think they would actually say?
6. How important do you think it is for students to learn about the nature of science from your text?

If "is important" – then "how do you believe your book helps with this?"
If "NOT important" – then "since such an intent is common in physics and science textbooks, can you tell me why this is NOT important to you?"

7. Overall, your book has a constant structure for chapters, a sort of 'template' – [brief description of this given for X's book]

What was the thinking behind this constant structure?
(Also probe to explore perceived purposes for each section.)

B. For the next set of questions I want you to consider the section of the book relating specifically to **electricity** [that is Chapters (A–B)]
8. In comparison with other sections of the book how would you rate the difficulty of writing this section? Did you try to present the material in this section in different ways to other sections of the book?
9. For this section did you attempt to present the material in a different way to other physics texts at this level?

[If *Yes*] In what way(s)?

10. Did you find any concepts in this section difficult to convey?

[If *Yes*] Which one(s), and why?

11. Since the book was published is there any aspect of this section you would now present differently?

[If *Yes*] Which aspect(s) and how would you change it?

C. One of the things that teachers often discuss when they are talking about teaching electricity is models and analogies.
12. What do you mean when you use the terms models and analogies?
13. Do you think that models or analogies are helpful or unhelpful for students at this level learning about electric circuits?

[If *Unhelpful*] Why?
[If *Helpful*] Which model or analogy? How is it helpful?

14. [IF "*Helpful*" is response to Qn 13] Think about students at years 7, 10, 12:

Do you think there are any differences in the sorts of models and analogies that are helpful for students at these different levels?
[IF "*Unhelpful*" is response to Qn 13] Think about students at years 7, 10, 12:
Do you think models and analogies would be helpful at these other year levels?

Part 2

A. I want to focus now more on the concepts of electricity.

1. (Show card with circuit containing a cell, a resistor/globe and a switch)

(a) On completing a course using your textbook, how would you expect students to explain when you close the switch

– why the globe lights up ?
– why there is a current in the globe?
What aspects of your book would assist students in achieving this understanding?
What understanding should students have before using your textbook?

(b) Is the explanation you expect students to have on completing a course using your textbook an understanding that a scientist would agree with?
(c) What is the evidence/basis for the scientific explanation?
(d) Do you consider it necessary to provide students at this level with this evidence?
(e) Think about students at years 7, 10, 12:

would you expect differences in student understanding of this circuit at each of these different levels?
(If Yes, what differences;
If No, come back to this with Qns 2–5 as appropriate)

(f) What do *you* consider to be the fundamental concepts for understanding a simple DC circuit such as this one [the one on the card for Qn 1 Part 2]?
(g) We [the researchers] have often been asked by students over the years about the effect on this circuit of adding a light globe –

in particular, if a second globe is added after the one there now *(draw this on circuit)* how does the first light globe 'know' that there are now two globes involved, and that there is now a lower circuit current.
If a student using your book asked you this, what response/explanation would you give?
[Qns 2–5 may have been answered in various sections of Qn 1 - lots of "playing by ear" assumed!! Reference to the circuit for Qn 1 is assumed for Qns 2–5.]

2. Using the same circuit could you explain to me what you mean by 'voltage'?

[If *potential difference* and *voltage drop* are not mentioned]
What do you think about the use of these three terms? For you do they mean the same thing?

3. Using the same circuit could you explain to me what you mean by 'emf'?
4. Using the same circuit could you explain to me what you mean by 'resistance'?

[If the meaning of *Ohm's law* not described] What is Ohm's law?

5. Using the same circuit could you explain to me what you mean by 'electric energy'? (What has it and where is it?)
6. Imagine we have a circuit with a cell and two resistors in series, as on this circuit diagram (*show diagram*) and we ask this question: "If the resistance of one of the resistors is increased, what happens to the current in the other resistor?" How would you expect a student using your book to approach answering this question?

B. There is one thing/are a couple of things I'd like to ask about [your book] and electricity.

7. [specific question about aspect of the book – detail cannot be given as this would potentially identify the book and hence the author or authors]

8. [second question specific to book – again cannot be reproduced]

C. And finally here are a few statements made by students.

What do you think each statement says about the understanding of the student who gave it? (Each statement to be on a card, and both read and placed in front of interviewee.)

9. *(A student considering a circuit containing a resistance R and a cell in series):* “Electrons flow out of the negative terminal of the battery, through the resistance R and back to the positive terminal of the battery.”
10. “When the current reaches the filament of the globe the resistance of the filament slows the current.”
11. “The energy the cell gives the electrons is called the voltage.”

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