Working Document

The Physics Enhancement Project

Becoming an expert teacher: Novice physics teachers' development of conceptual and pedagogical knowledge

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Introduction

There is an alarming decline in the number of qualified physics teachers in many countries around the world. For example, in the UK the number of physics graduates entering teaching is at an all-time low (IoP, 2001). Furthermore, a high proportion of physics teachers in both the UK and Norway are approaching retirement age (Angell, Henriksen, & Isnes, 2003; EPS, 1999). There is also a concern that the number of pupils choosing physics in upper secondary school is too small to ensure an adequate supply of physics teachers. Many studies points to the negative attitude to science in general and to physics in particular amongst young people (Osborne, Simon, & Collins, 2003). One factor may be that physics is often taught by teachers who lack specialist knowledge. For example Sparker (1995) suggests that the reason more pupils study physics in Scotland is because physics teaching is carried out almost entirely by qualified physics teachers. One response to this problem is to enable science graduates without a subject specialism in physics to enter training courses that develop their physics subject knowledge and enable them to qualify as specialist physics teachers. Such a course has recently started in the UK (http://www.gatsby.org.uk). The aim of our study is to examine these trainee teachers' experiences alongside those of trainees with specialist physics backgrounds, and to explore the trainee teachers' conceptual and pedagogical knowledge along with those of experienced physics teachers.

Many studies have provided insights about how student teachers and beginning teachers encounter their teaching experience and their ability to reflect on their practical experience (Penso, Shoman, & Shiloah, 2001), how their beliefs about science and science teaching influences classroom practice (Brickhouse & Bodner, 1992) and how induction programs are essential in addressing the pedagogical and content needs of science teachers (Luft, Roehrig, & Patterson, 2003). Furthermore there are studies of prospective science teachers' beliefs concerning constructivist teaching practice (Haney & McArthur, 2002) and studies of beginning teachers' and experienced teachers' conceptions of the concept of prior knowledge (Meyer, 2004). And there are studies which have examined the differences between expert and novice teachers (Hogan, Rabinowitz, & Craven, 2003) and the professional development of beginner teachers (Kagan, 1992). However, there have been few studies following teacher trainees through their initial training and into the first years of classroom teaching. Ours is a three year longitudinal study following the development in knowledge/expertise of beginner physics teachers from a range of science subject backgrounds and making comparisons with the knowledge/expertise of expert physics teachers. We take this knowledge/expertise to include an understanding of the concepts of physics (content knowledge) and how to teach it (pedagogical content knowledge). Shulman (1987) explained pedagogical content knowledge as:

> *…pedagogical content knowledge is of special interest because it identifies the distinctive bodies of knowledge for teaching. It represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organised, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction. Pedagogical content knowledge is the category most likely to distinguish the understanding of the content specialist from that of the pedagogue (p.8).*

In this paper we present data from the first phase of the study and examine teachers' (both beginners' and experts') written responses to science questions set in a pedagogical context. We are focusing on a restricted part of the framework in this paper and at this stage of our research programme. Specifically, we address the following research questions:

1. What are the key features of the knowledge bases (relating to content, teaching strategies, pupils' reasoning) which beginner and expert teachers draw upon in thinking about the design of science instruction?
2. What are the key differences in those knowledge bases?
3. What can be said about how those differences in knowledge bases relate to the pedagogical practices of novice and expert science teachers?

Methods and Sample

A written questionnaire containing eight items was used to probe respondents' thinking about content and pedagogical issues within a range of physics content areas. The questions were carefully designed to shed light on how the respondents would express their content knowledge in a pedagogical context. For example how they referred to possible misconceptions, the pupil's possible prior knowledge or how they sequenced their answers.

A total of 41 trainee physics teachers from six universities in the UK completed the questionnaire. This sample includes 17 trainees without a degree specialism in physics. Prior to their teacher training course these trainees had completed a six month course to improve their understanding of physics topics. Sixteen expert physics teachers also completed the questionnaire. These expert teachers all had at least three years teaching experience and were known to the authors as exemplary teachers of physics. Responses were categorised and coded inductively. Reliability was checked by independent coding of responses by the researchers. This resulted in more than 80 % overall coding agreement. The responses were then reread several times and interpretations were modified and refined during intensive discussions. The final categorising and coding were then based on these common interpretations. The coding scheme is shown in the appendix.

We recognise that probing teachers' pedagogical content knowledge is a complex task (Loughran, Mullhall, & Berry, 2004), and in the broader context of our study, analysis of written responses is used as a starting point for a more detailed analysis of teacher expertise that draws upon classroom observations and post-lesson teacher interviews.

This is not a questionnaire survey where random samples from two different populations are compared. Statistical significance testing based on a known sampling distribution is therefore not applicable. However, nonparametric methods could be used when nothing is known about the parameters of the variables of interest. Nonparametric significance testing does not rely on the estimation of parameters describing the distribution (e.g. the normal distribution) of the variables. In the analyses we have used Mann-Whitney U significance test for aggregated data across all the questions. The *p*-values (asymptotic significance) are shown in brackets where applicable.

Data analysis and results from the questionnaire survey

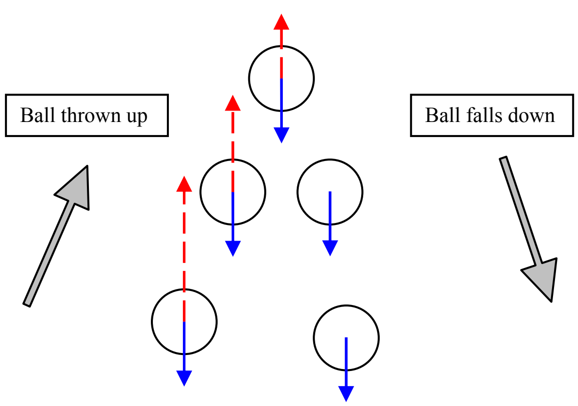
The overall analyses of the conceptual content of responses from both beginners (physics specialist and non-specialist) and experts revealed very few misconceptions. In particular, trainee teachers without a degree specialism in physics showed a level of physics concept understanding at the start of their training course (after the six months physics enhancement course) broadly equivalent to that shown by trainee teachers with specialist physics degrees. The biggest differences within the sample related to *pedagogic knowledge* rather than conceptual reasoning. Responses from trainee teachers tended to focus mainly on conceptual understanding.

All the responses were as mentioned above categorised and all the variables were put into one of two broader categories; "content" or "pedagogy". In the following diagrams results for individual variables are shown. The bars in these diagrams represent the percentage of each group (students and teachers) who have given a valid response for each of the variables (coded categories). Responses could be coded into more than one category. Some categories have very few responses and are omitted from the figures. However, some of these categories are commented on in the text.

Figures showing content "sum" and pedagogical "sum" are also shown. One point is given for each correct/valid content variable and for each productive/valid pedagogical variable. A zero value is given for incorrect and unproductive responses.

Ball in the air (item v1)

You are teaching mechanics to a Year 10 class. One of the pupils, John, argues that the forces acting on a ball, when it is thrown up in the air, are as follows (the diagram shows the ball after it has been thrown).



John says:

'When you throw the ball up, it sets off with a BIG upward force but this gradually runs out and gets less, so that at the top the upward force is balanced by gravity and the ball stops going up. The ball then falls because of the pull of gravity'.

a. Do you think that John is correct in what he says?

b. What would you (the teacher) say in reply to John?

This was the first item in the questionnaire, and John is expressing the very common misconception that there always must be a force in the direction of motion. It is known from a large number of studies that this sort of problem is often a very difficult for pupils (Angell, 2004; Duit, 2004; Viennot, 2001). In this study, however, we were primarily interested in how the beginning teachers and the expert teachers responded to the problem in this "authentic" teaching context.

Most students and expert teachers answered *no* to the first question. There are however 10 students (but no experts) who wrote that John is almost correct or that it is something correct in what he says; for example that the ball falls because of the pull of gravity. Some misconceptions were also revealed as this answer from one of the students illustrates:

Yes, he understands that the forces are balanced at the peak.

However, as already mentioned, relatively few misconceptions were revealed and it appears not to be a significant problem within our sample.

The result of the second question is shown in Figure 1 and Figure 2.

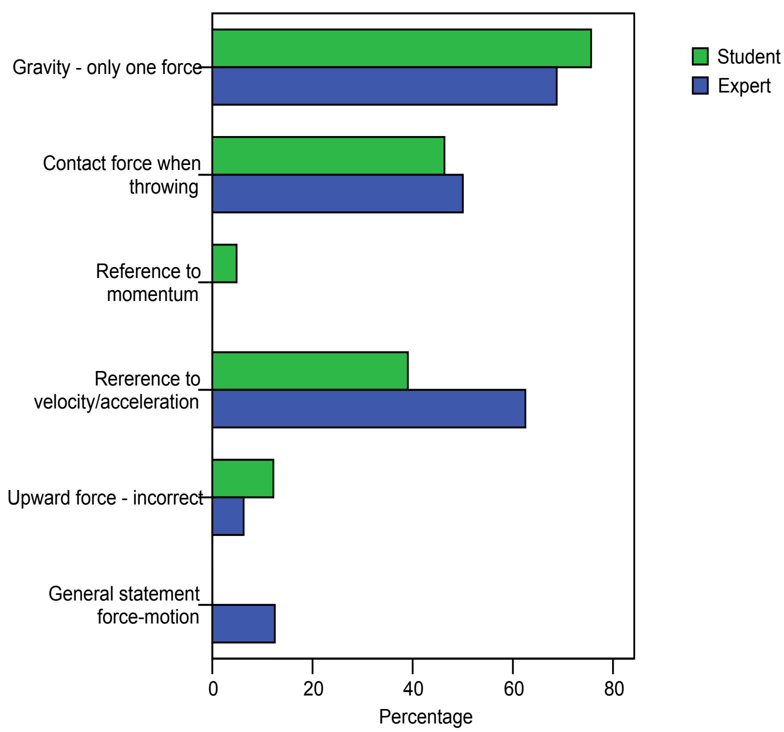


Figure 1. Ball in the air. What would you (the teacher) say to John? The figure shows the prevalence of different content categories from students and expert teachers respectively.

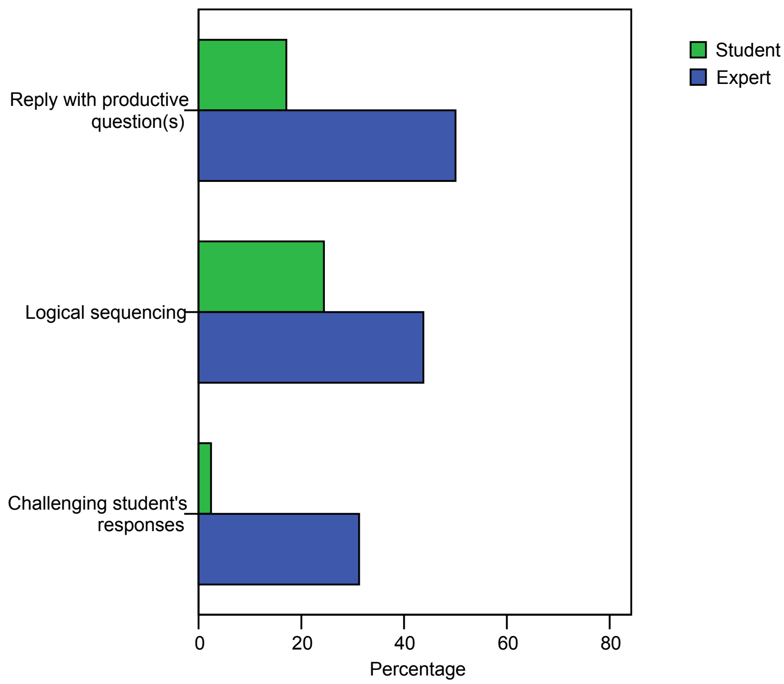


Figure 2. Ball in the air. What would you (the teacher) say to John? The figure shows the prevalence of different pedagogical categories from students and expert teachers respectively.

Figure 1 and Figure 2 shows that the biggest differences between the students and the teachers were related to *pedagogic knowledge* rather than conceptual reasoning. The expert teachers more extensively used a logical sequencing in their responses and they were more likely to reply with a question and to challenge students' conceptions. However, only two expert teachers and none of the students mentioned everyday thinking or typical alternative conceptions.

Many of both the teachers and the students referred not surprisingly to gravity as the only force acting and that a force upwards only was acting when the ball was in contact with the thrower's hand. The subject knowledge seemed to be quite good within both groups, and very few exposed the misconception of a force in the direction of motion when the ball is moving upwards. The teachers were also more likely to refer to acceleration and change in velocity. Very few referred to momentum, energy or for example the effect of air resistance.

The following is a quotation from a student who gave an excellent response, however only focusing on the content knowledge.

> *You apply a big upward force when you let go. Once you let go there is only one force acting downwards on the ball and that is gravity. The initial throw gives the ball upward movement. Gravity is opposing the movement, so it slows down, stop, then speed up as it falls back to earth*

The following expert teacher explicitly challenged the pupil's view and the quotation is a good example of how an expert uses his or her pedagogical experience along with the content knowledge.

I would tell him he was partly correct – and that his explanation of why the ball fell was right. I would ask him what applies the upward force after the ball leaves the thrower's hand? – Mechanical forces need contact to apply them. Hopefully he would realise that there could not be an upward force. I would then use his own explanation of why the ball fell (i.e. gravity) in conjunction with Newton's 1st law to explain why the ball slowed down AND why it left the thrower's hand with an upwards velocity.

Some of the students also took pedagogical considerations into account by replying with questions as the following citation illustrates:

When you let go of the ball at the end of your throw are you still applying a force? Where can the big upward force come from? If you think about unbalanced forces – the ball must slow down + start falling because of the action of gravity

Even though the overall analyses of the respondents' conceptual understanding revealed very few misconceptions; a small proportion of the students demonstrated some misconceptions as the following illustrates:

As the ball increases in height the amount of gravitational potential energy it possesses increases. Eventually this equals the upward force and the ball is stationary.

Figure 3 shows the calculated sums for valid responses coded as content and pedagogy respectively. The expert teachers put notably more pedagogical considerations into their responses, whilst the number of content arguments is quite similar for both groups. There were seven valid content and eight valid pedagogical categories. The Mann-Whitney U test showed that for the category "pedagogy" there was statistical difference between the two groups (*p*-value < 0.05), but not for the "content" category.

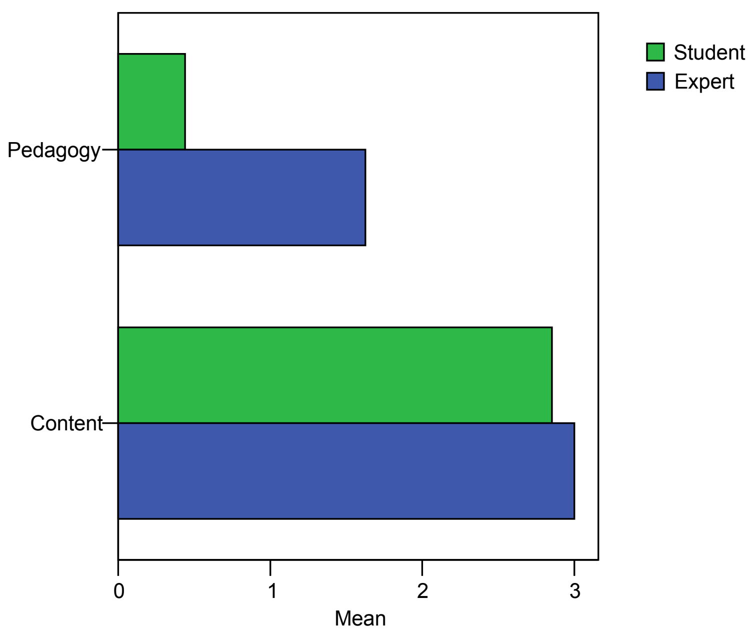


Figure 3. Ball in the air. Content "sum" and pedagogical "sum"

Skater (item v2)

This item is about forces acting on a skater when she is slowing down. Mary, the pupil, expresses a common misconception that there must be a force in the direction of motion.

You are planning a top-set Year 11 revision lesson about forces. In the science staffroom you find an OHT showing a skater gliding across an ice rink. The skater has just pushed-off and is very gradually slowly down.

a. On the picture above show how you would draw the *forces* acting on the skater when using the diagram in the classroom.

Mary, one of your pupils, says:

'As long as the skater is moving forwards there must be a force pulling her - that's for certain!'

b. How would you respond to Mary?

For part (a) of the question the respondents were asked to draw the forces acting on the skater. Three of the experts did not draw force arrow. They were only answering the question how they would respond to Mary. Seven of the sixteen experts did not draw vertical force arrows at all, and five of them explicitly said they did not draw vertical forces in order not to complicate the diagram for pupils. None of the beginning teachers made such an argument. Neither the experts nor the students were precise when they drew force arrows. Both the position and the length of the force arrows were in many cases inaccurate.

There were also inconsistencies in the answers from some of the students. For example one student had drawn an arrow indicating a force acting in the direction of motion. But the student at the same time included a productive question asking where the pulling force could be. Another student who also had drawn an arrow in the direction of motion gave a correct explanation to Mary. These students might have drawn arrows to indicate the direction of motion. However, on the whole the drawing of force arrows was not as skilful as one may possibly expect!

Figure 4 shows the *pedagogical* categorised responses for the trainees and the experienced teachers, and Figure 5 shows the *content* categorised responses.

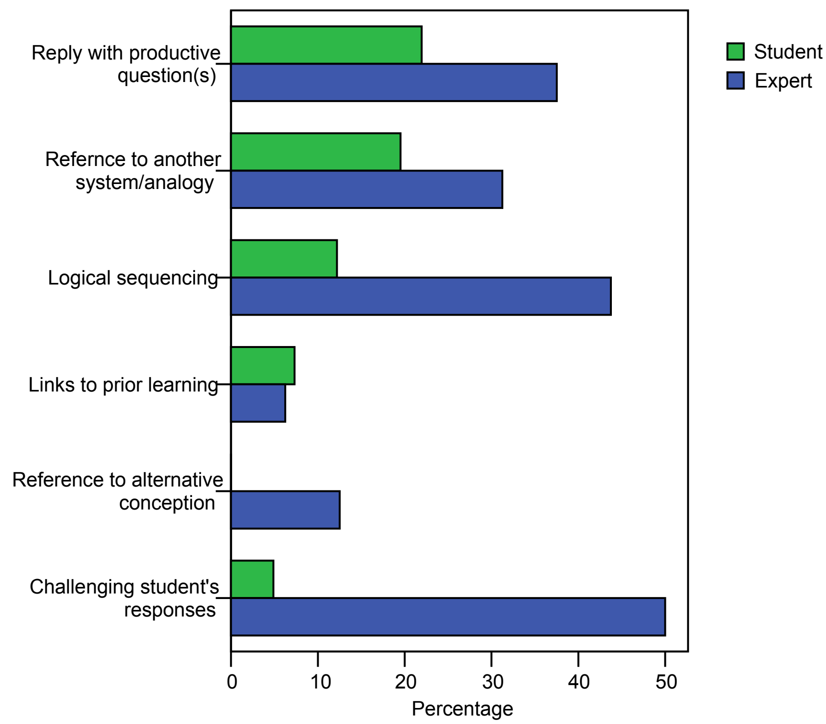


Figure 4. Skater. What would you respond to Mary? The figure shows the prevalence of different pedagogical categories from students and expert teachers respectively.

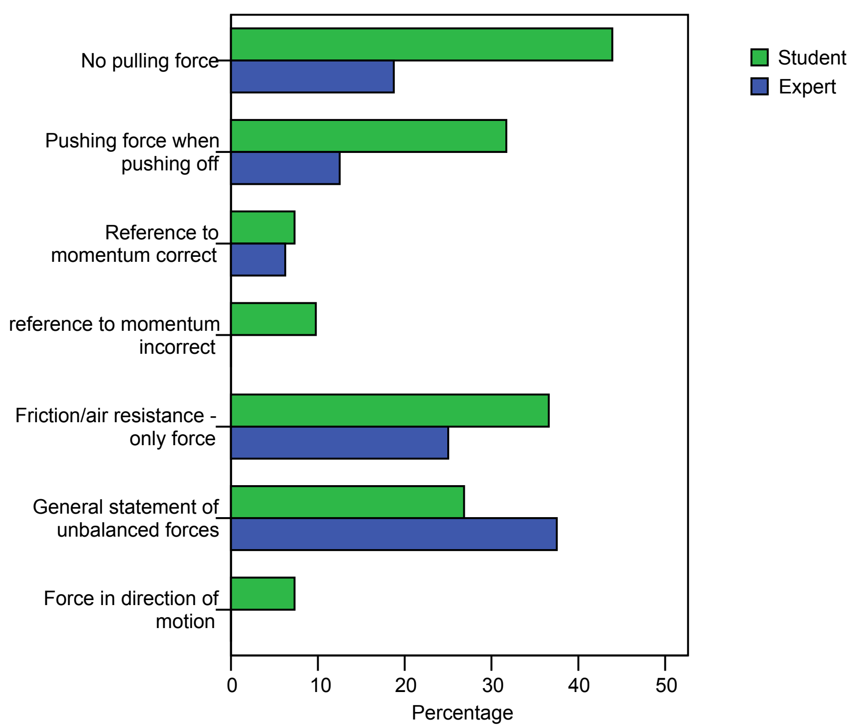


Figure 5. Skater. What would you respond to Mary? The figure shows the prevalence of different content categories from students and expert teachers respectively.

Responses from trainee teachers tended to focus mainly on conceptual understanding. For example, here is one trainee's response to part (b) of the question:

> *"The skater glides after pushing off. There is no forward force after the push off and the skater is as a result always decelerating."*

In addition very few referred to momentum and almost nobody reasoned with energy. The expert teachers, however, more often included pedagogic insights in their responses (see also Figure 6). They were more likely to analyse or challenge Mary's claim about the pulling force, and many of them also provided a logical pedagogical sequence in their responses, indicating where they would wish to start and how they would proceed from here towards an appropriate understanding. For example, the following expert teacher refers to everyday experience and is challenging Mary's ideas with a question:

> *"Remember forces change movement, we are used to having to provide a force to balance friction, here with very little friction the skater nearly keeps going. What is pushing/pulling her?"*

Another expert teacher suggested analogies in addition to using questions:

> *"What is causing this force? If you were in space, imagine dropping a spanner, describe its motion. When you are riding a bicycle, what happens if you stop pedalling? What is pulling [the] bike along?"*

In Figure 6 we have summarised the content and the pedagogical categorises, and the differences between expert teachers and trainee students are elucidated. Experts drew on pedagogical arguments to a significantly (Mann-Whitney U test: $p < 0.05$) larger extent than the students did.

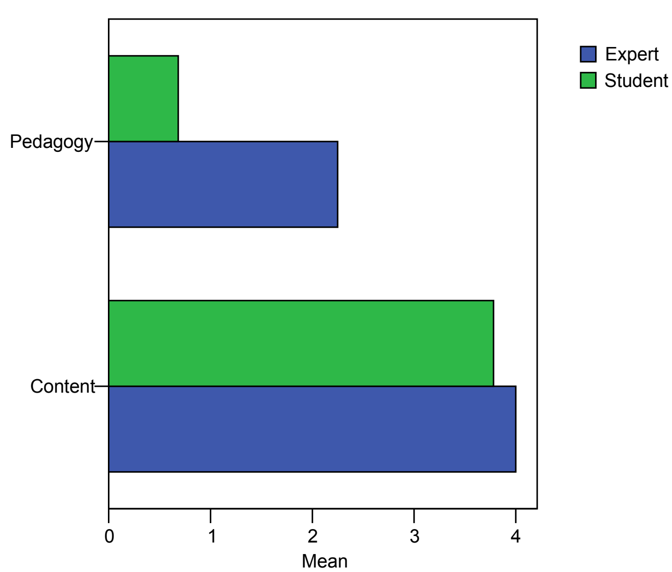


Figure 6. Skater. Content "sum" and pedagogical "sum"

In the dark (item v3)

This item deals with the fact that both humans' and cats' eyes must receive light in order to see. Ann in this task expresses the common misconception that cats' eyes are "active" in the sense that cats can see independent of incoming light (Galili & Hazan, 2000; Viennot, 2001). Here the trainees and the teachers were asked what they would *do* in class in the described situation.

> You are teaching a lesson about light and seeing to a year 7 class. One of the pupils, Ann, puts her hand up and says:
>
> 'Yes, but my cat can see in the dark!'
>
> What would you do in class to persuade Ann that neither cats nor humans can see in the dark?

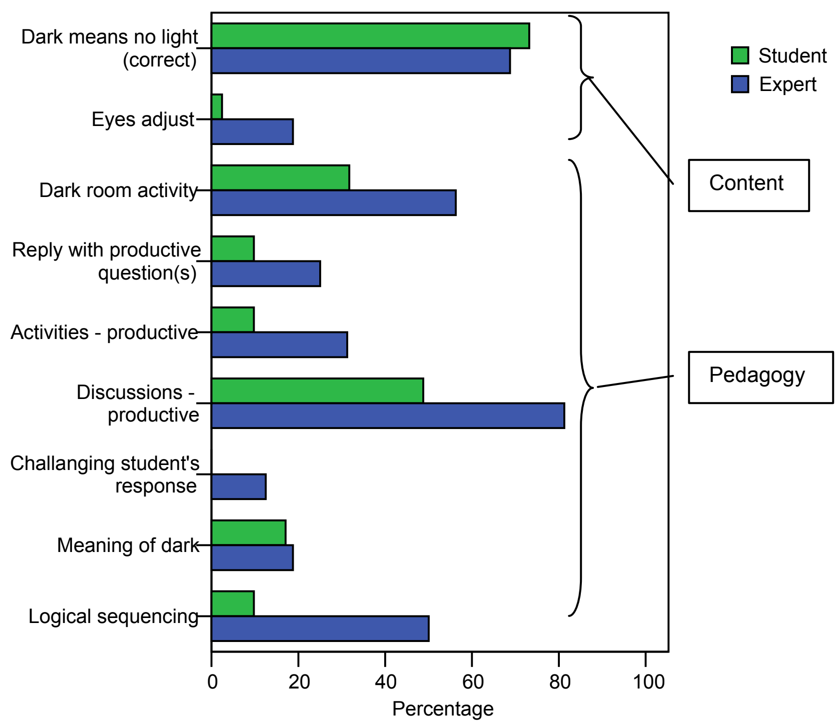


Figure 7. In the dark. What would you do in class? The figure shows the prevalence of different categories from students and expert teachers respectively.

The same pattern emerges from Figure 7 as for the previous tasks. In particular the differences between the teachers and the students were noteworthy for proposed activities, productive discussion and a logical pedagogical sequence in their responses. Most trainees and teachers conveyed a correct understanding of the physics involved in the task; emphasising that the eye must receive light in order to see or that *dark* means no light at all.

The question focused on what you would do in class to persuade Ann, but many students did not propose activities as the following response illustrates:

> *That's not true. Cats are better at seeing at low light levels. Even at night there is light, some stars, the moon and the street lights. If there was no light at all then your cat would not be able to se at all.*

Some respondents were also focusing on the cats' uniqueness or that cats can see in lower light levels as the following two quotations from students show:

> *(…) Explain that cats have evolved advanced methods for getting around in the dark including whiskers and acute smell.*
> *Explain that cats can see better than humans, i.e. in lower light levels, but that light still has to bounce off an object for it to be seen. (…).*

The following quotation is the start of an extensive response from an expert teacher who relates the answer to basic physics combined with an activity. The response is also an example of logical sequencing.

> *I would restate the idea that both human and animals see by reflection of light and so in order to see we need some light. Following this I would draw a distinction between dark (low light level) and blackout (complete absence of light). If possible I would then use a blackout in the lab to show that you cannot see objects if there is no light.*

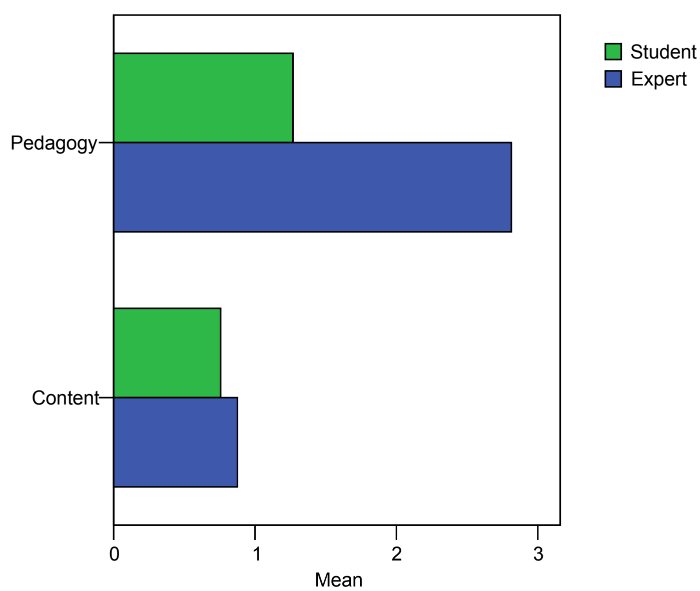


Figure 8. In the dark. Content "sum" and pedagogical "sum"

Figure 8 shows over again that even though they were explicitly asked to do so, the trainees were significantly less likely to give answers related to pedagogical reasoning than the experienced teachers were (Mann-Whitney U test: $p < 0.05$).

Snowman (item v4)

This item is focusing on the concepts of heat and energy transfer. Part (a) of the question deals with physics content, while the second part deals with possible pupil responses and thereby likely misconceptions about heat and energy.

> A teacher at your school, Judy, is preparing a Year 9 lesson about heat. She is a biology specialist and often asks you about possible teaching approaches. One idea that she has seen in a physics book is to ask pupils the following question at the start of the lesson:
>
> Would putting a coat on a snowman keep it warm?
>
> a. Judy wants to be sure that she understands the correct physics behind this question. What would you tell Judy? Does the coat keep the snowman warm?
>
> Judy is also unsure about how her Year 9 class might respond.
>
> b. What suggestions would you make to Judy about likely *pupil responses* to this question? List your ideas below:

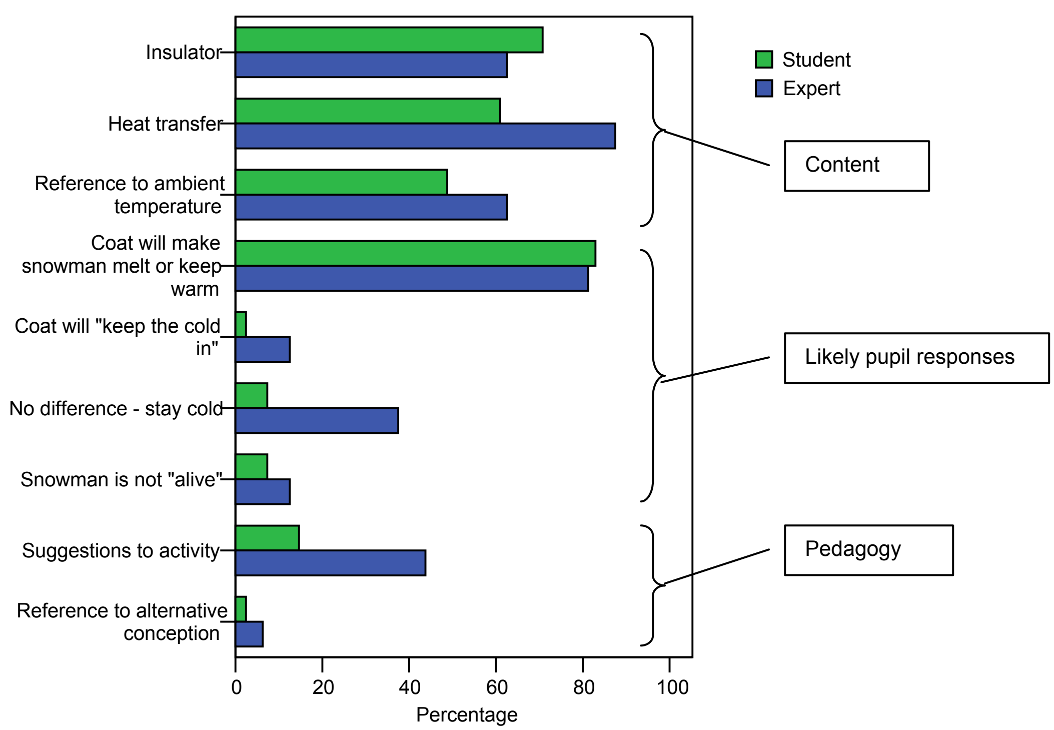


Figure 9. Snowman. Does the coat keep the snowman warm, and what could be likely pupil responses to this question? The figure shows the prevalence of different categories from students and expert teachers respectively.

As Figure 9 shows, there are no striking differences between the two groups if we look at the content related part of the responses, and almost no one exhibited any misconceptions. For example an expert teacher wrote:

> *Because the coat is made of insulating material it will reduce heat energy transfer. If the temperature of the air is greater than the temperature of the snowman then the coat will reduce heat energy transfer from the air to the snowman: The coat will help to keep the snowman cold!*

And a student:

> *The coat reduces the rate at which heat travels. If the snowman is cold, and the outside warmed up, then a coat would keep the snowman cold for longer.*

Furthermore, both groups suggested that the most likely pupil responses would deal with that the coat was making the snowman melting or was keeping him warm. Very few, however, pointed to the expected misconception that the coat would "keep the cold in". The expert teachers also to a larger degree proposed productive discussions or activities in the class. However, respondents were only asked for content and likely pupil responses.

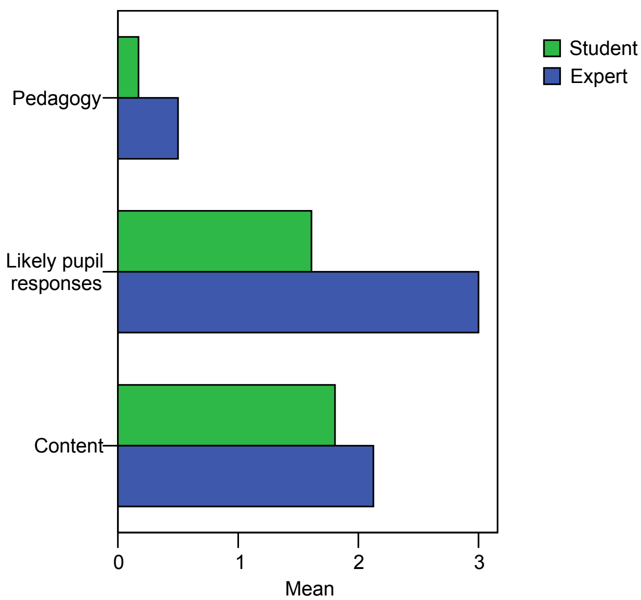


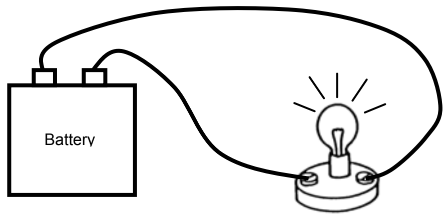
Figure 10. Snowman. "Sums" of content, pupil responses and pedagogy

Figure 10 shows that the differences in the responses between students and teachers were not as prevalent for this item as for many of the others. This might be due to the way this item was phrased, i.e. the answer is supposed to be to a teacher colleague. Therefore few of the respondents included pedagogical perspectives in their answers. However, the expert teacher proposed notably more likely pupil responses (Mann-Whitney U test: $p < 0.05$).

Electric charge (item v5)

This was a multiple choice item probing some simple but fundamental knowledge about charges and electric circuits.

In this circuit, the bulb is lit.



Read each of the statements below about *what is happening in the battery*. For each statement, put a tick in one box to show if you think it is **correct** or **incorrect** or **don't know.**

	correct	don't know	incorrect
(a) Before the battery is connected, there are no electric charges in the wire. When the battery is connected, electric charges flow out of it into the wire.	☐	☐	☐
(b) There are electric charges present in the battery and the wires all the time. The battery makes them move around the circuit.	☐	☐	☐
(c) Chemical reactions in the battery make electric charge, which then flows round the circuit.	☐	☐	☐

Read each of the statements below about *what is happening in the bulb*. Then put a tick in one box to show if you think it is **correct** or **incorrect** or **don't know.**

	correct	don't know	incorrect
(d) The electric charges are used up in the bulb, and converted into light.	☐	☐	☐
(e) Collisions between the moving electric charges and the fixed ions in the filament make it heat up and glow.	☐	☐	☐
(f) The same number of charges return to the battery every second as leave it. No charges are used up.	☐	☐	☐

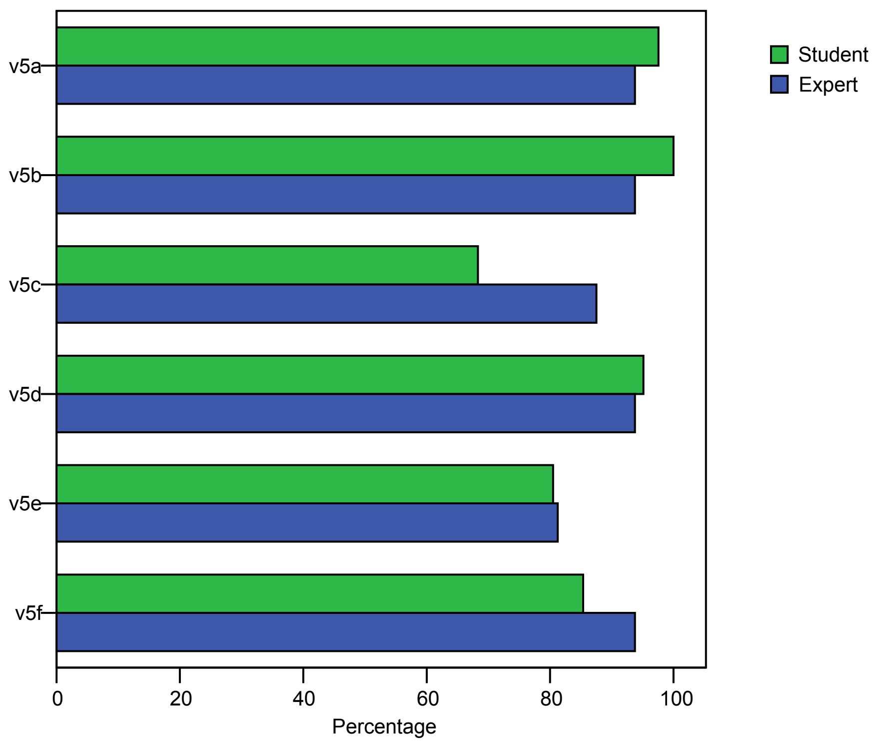


Figure 11. Electric charge. The figure shows the percentage of correct responses from each group. The labels on the vertical axis correspond to the statements given in the task.

Most of the respondents gave correct answers to these questions, and there were small differences between the expert teachers and trainee students. However, one might have expected that at least all the experts had answered this item correctly, but they did not. This might be due to some confusion about either the meaning of the question or the meaning of at least some of the alternatives they had to choose from.

Series circuit (item v6)

Simple electric circuits and pupils' understanding of fundamental concepts in electricity has been the focus of a huge amount of research during the last decades (e.g. Duit, Jung, & Rhoeneck, 1985; Mulhall, McKittrick, & Gunstone, 2001). In this task, however, we are focusing on which key points that will need to be emphasised to pupils as one moves from the single battery/bulb circuit to presenting an explanation of how a series circuit (one battery and two bulbs) works. By key points we mean the content knowledge one would emphasise and in what (if any) sequence one would present these key points.

> You are teaching a bright Year 10 class about electric circuits. You go through the basic ideas of charge, current and energy transfer and they seem to have no problems with your explanation of how a simple one battery/one bulb circuit works.
>
> In the next lesson the focus is on *series* circuits.
>
> What, do you think, are the *key* points which you will need to emphasise to pupils as you move from the single battery/bulb circuit to presenting an explanation of how a series circuit (one battery and two bulbs) works?

Figure 12 presents the results from this item. The answers from expert teachers and trainee students were to some extent relatively similar. However, the experts were more likely to provide some logical sequencing in their responses and they also emphasised the energy aspect significantly more than the trainee students. Consequently one could argue that the experts use of the concept of energy have a more fundamental approach to the problem than the students. Although this was not explicitly asked for, the experts were a little more likely to show some pedagogical reasoning related to the key point they presented. For example some of them (although few) referred to pupils' curriculum starting points, everyday thinking or made links to prior learning.

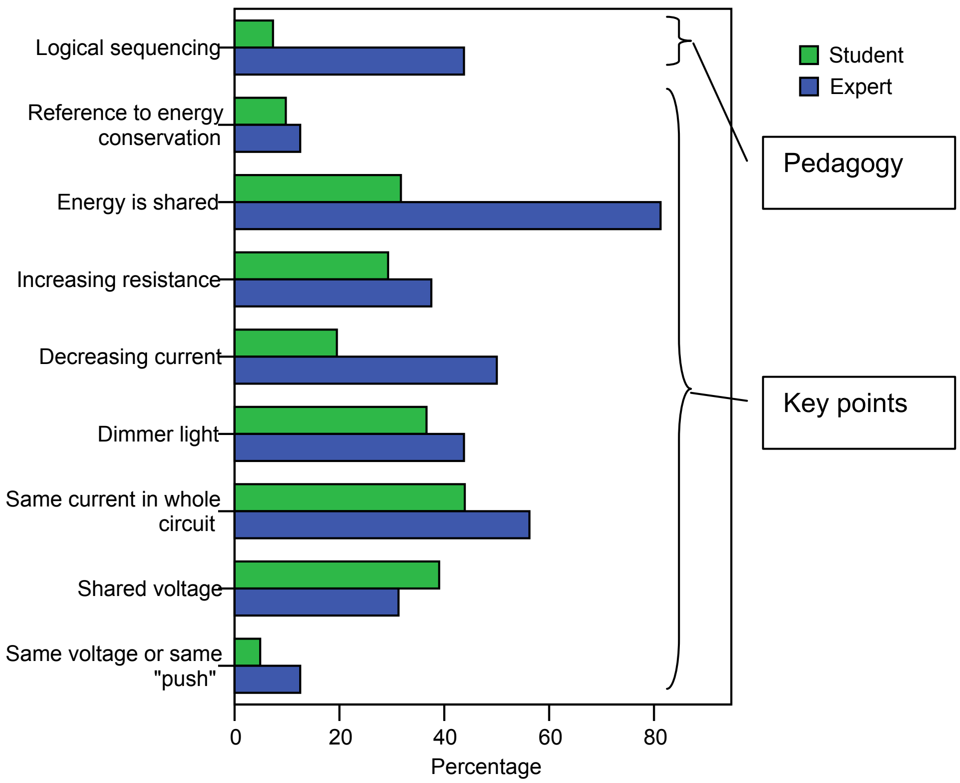


Figure 12. Series circuit. The figure shows the prevalence of different categories from students and expert teachers respectively.

For example the following expert teacher emphasised some logical sequencing and the relation to the one battery/one bulb circuit.

> *As you add the extra bulb: a) the bulb get dimmer, b) the resistance of the circuit goes up, c) the current goes down (same push), d) energy of each charge is shared between 2 bulbs. (…)*

The following student response is also quite good emphasising some key points:

> *Current is the same in all parts of the circuit. Voltage across the bulbs is split equally since power = IV then bulbs are half as bright. Power = Energy/time. Energy of the battery is "shared" between the bulbs.*

The next citation shows a less elaborated response from a student:

> *The key points are the movement of the current before, between and after the bulbs and the measurement of the voltage across the battery and the two bulbs.*

Figure 13 illustrates the main differences between the two groups. The experts gave some more comprehensive answers, and as already mention the pedagogy was a little more salient than for the students.

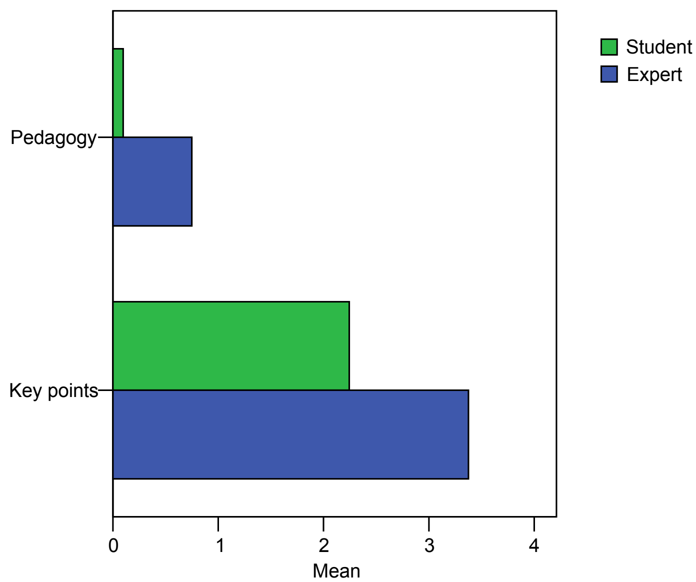


Figure 13. Series circuit. "Sums" of key points and pedagogy (for both; Mann-Whitney U test: $p < 0.05$)

Electrical analogy (item v7)

Analogies are certainly often used in science teaching. This item is focusing on an electrical analogy, and particularly on its strengths and weaknesses.

Bob, a colleague in the science department at your school is talking in the prep room about 'teaching electricity'. He is very enthusiastic about using the analogy of vans carrying bread to help explain the working of electric circuits:
'Yeah, I always get them to think of the charges in the electric circuit as being like a continuous line of bread vans which move round between a bakery and a supermarket, picking up bread at the bakery and delivering it to the supermarket. The vans are just like charges, the bread is the energy, the bakery is the battery and the supermarket the bulb. It's simple!'
All analogies have their strengths and weaknesses. List below, what you think, are any strengths and weaknesses of Bob's analogy: Strengths: Weaknesses:

Figure 14 shows that the pattern in the responses for the strengths of the analogy is rather similar for the two groups. This is the only item where the categories valid and not valid *other responses* are used quite substantially because of too many very specific suggestions. However, Figure 15 first of all shows that the expert teachers to larger extent suggested weaknesses of the analogy. For example only a small proportion of the trainees mentioned the weakness that energy might be seen as a substance (to be delivered) in this analogy, whereas almost the half of the experienced teacher mentioned that. For example as an expert teacher wrote:

> *1) Doesn't fully help with breaks in circuit after bulb as vans would continue. 2) "Energy" is not a substance to be delivered – material quantities like bread could pile up if not used.*

However, some students also commented on weaknesses as the following example illustrates:

> *Pupils may ask where energy for vans comes from. Energy from the battery "bakery" is not driving the vans around.*

It is also striking that there is a disagreement within our sample for this item. There are answers which suggest that the model *can* explain series and/or parallel circuits and there are answers that state that the model *cannot* explain series and/or parallel circuits.

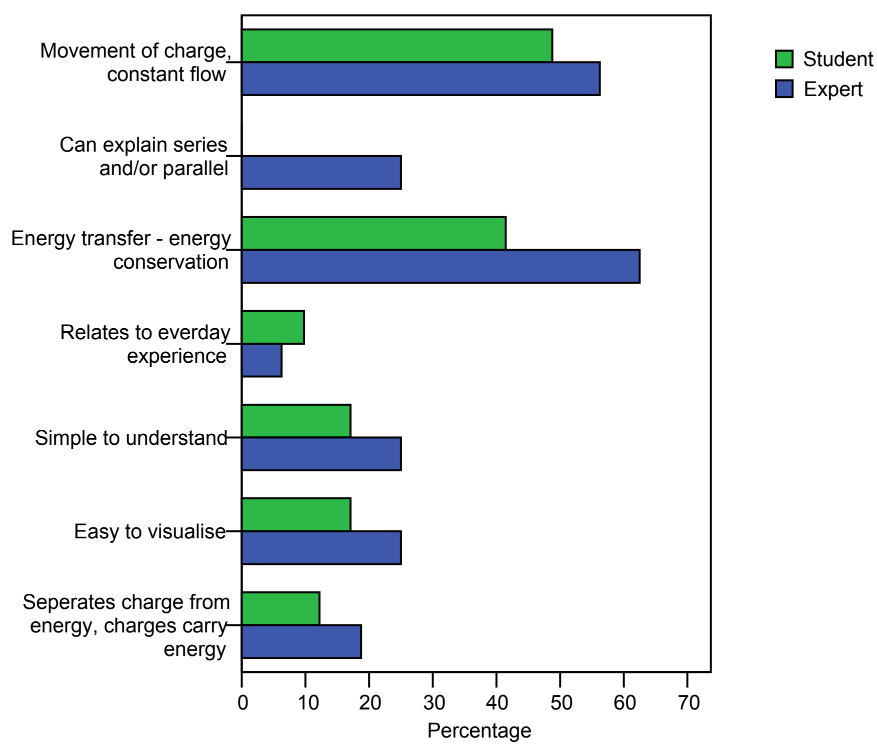


Figure 14. Electrical analogy. Strengths. The figure shows the prevalence of different categories from students and expert teachers respectively.

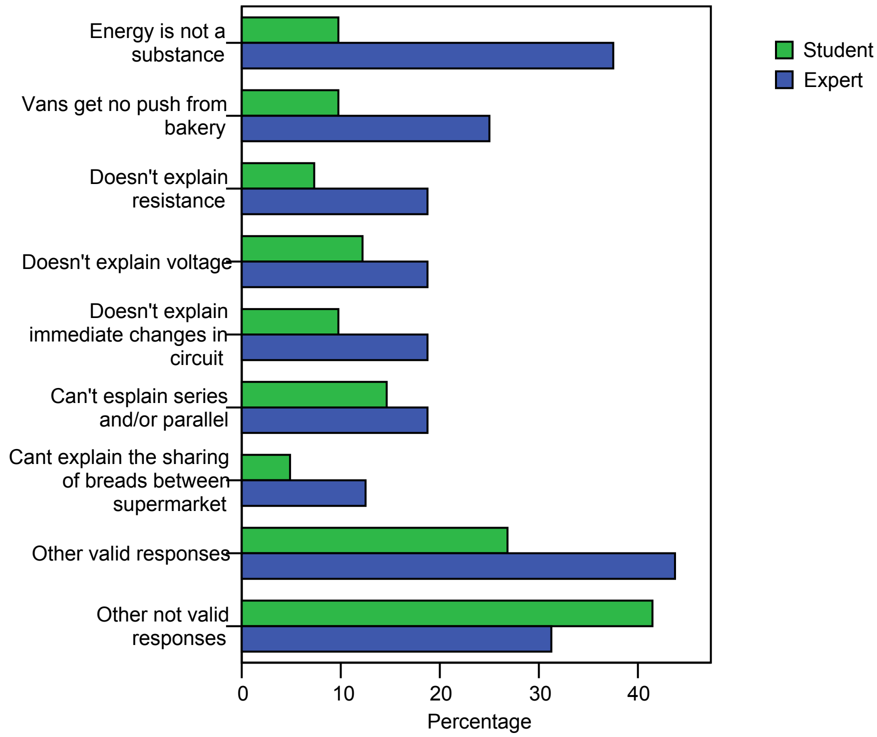


Figure 15. Electrical analogy. Weaknesses. The figure shows the prevalence of different categories from students and expert teachers respectively.

The fact that the students in this study seem to be more conscious of the strengths of the analogy than the weaknesses might reflect their own experiences with analogies in their own education which mostly might have focused on what the analogy can explain and not so much on what it can not explain. Experienced teachers will have used teaching analogies a great deal in the classroom and are therefore more likely to recognise the importance of pointing out the weaknesses of an analogy as well as its strengths. Harrison & Treagust (2000) also points to the need for teachers to socially negotiate model meanings with their students and to regularly remind students that all models break down somewhere and that no model is "right". Likewise; the unsatisfactory understanding of the nature of "model" implies that it should be the subject of pre-service education (Justi & Gilbert, 2002)

All the variables of the strengths and weaknesses of the analogy are coded into the main category of pedagogy. Figure 16 shows the result of the "sum" of weaknesses and strengths for this item (Mann-Whitney U test: $p < 0.05$). The teachers had not surprisingly more suggestions than the trainees, and as mentioned above, that was mostly due to the suggestions of weaknesses.

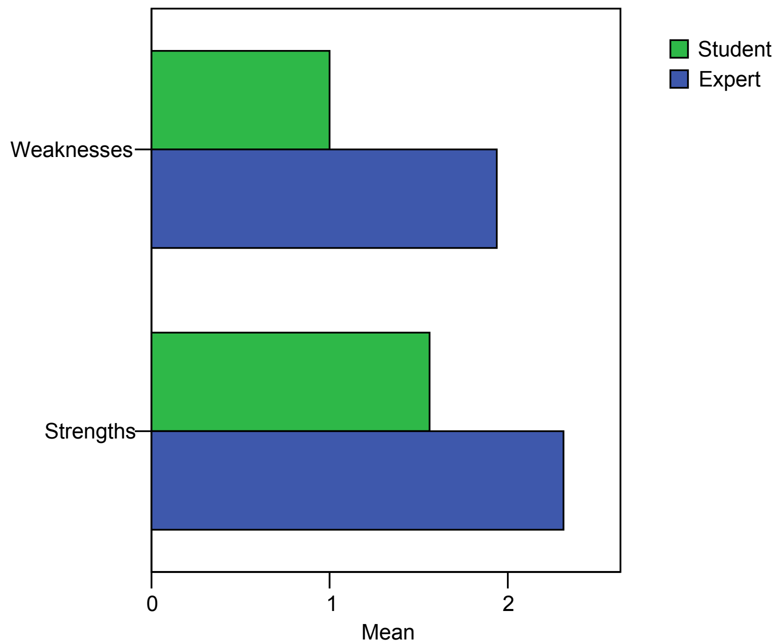


Figure 16. Electrical analogy. "Sum" of weaknesses and strengts.

Energy conservation (item v8)

The last question is about energy and energy conservation. As for all the other items in this booklet, we are trying to probe the respondents' ability to put their content knowledge in a pedagogical context.

A Year 10 pupil, Sudha, asks you the following question:

In our last science lesson you told us that energy is always conserved…that it can't just appear from nowhere or just disappear. But I just heard something on the TV last night about them running out of energy in some country or other, and having to build a nuclear reactor. I don't get it! If energy is always conserved, how can we run out?

How would you answer Sudha?

The result is shown in Figure 17. The differences between the expert teachers and the trainees were not very big, except that the experts were more likely to provide a logical sequence in their response. Most of the respondents were focusing on the fact that energy is conserved, but not in a useful form and that energy resources are used up. About 40 % of both groups also provided a clarifying example or some productive pedagogical suggestions.

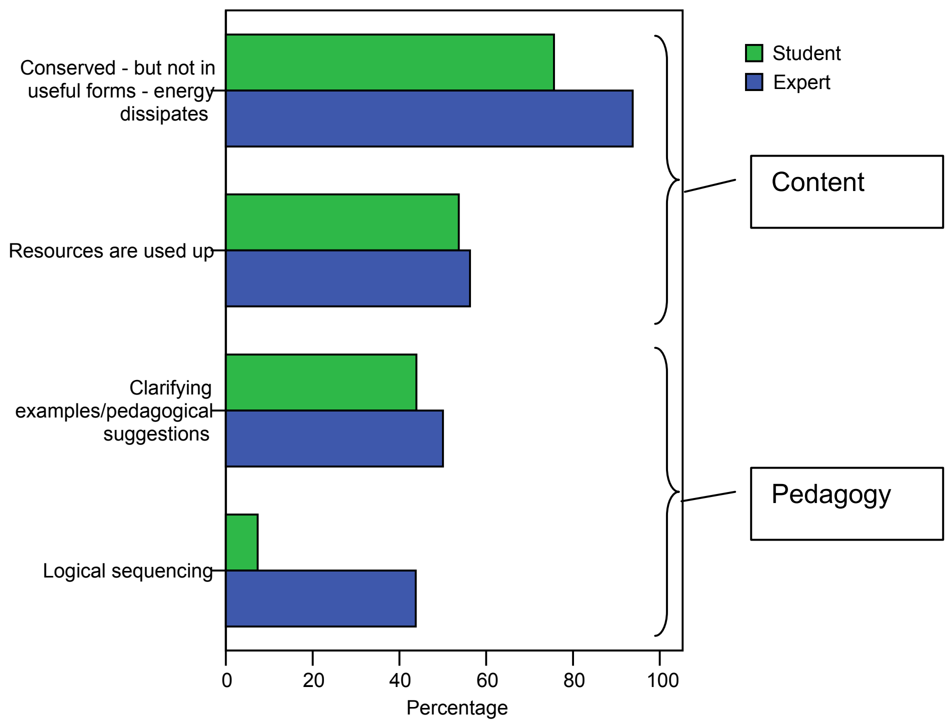


Figure 17. Energy conservation. The figure shows the prevalence of different categories from students and expert teachers respectively.

Here are two examples from two expert teachers:

> *When energy changes form it is conserved (e.g. electricity → heat + light), but the energy at the end of the process is not always useful. The country has run out of* <u>*sources*</u> *of energy; they do not have enough energy in useful forms (such as chemical energy in coal) that can be converted into other forms (such as electricity, for example).*
>
> *I would explain that they had not run out of energy – but energy resources (i.e. the means to generate energy in a useful form). So by building a nuclear reactor they can use a new energy resource to generate energy in a useful form i.e. electricity. (...).*

A number of students also pointed to the fact that it is the energy sources that are running out as the following two examples illustrate:

> *Energy hasn't run out, the energy source has run out. The country has converted all of its energy, the energy has dissipated into the surrounding environment.*
>
> *I would explain that we can run out chemical energy stores, fuel, which we need to convert into useful heat and electrical energy.*

These examples also show that the experts more than the students provided some logical sequencing in their answers.

Figure 18 shows the summary of all content and pedagogy categories for this item. As already mentioned, the differences were small (Mann-Whitney U test: $p = 0.09$ for the pedagogy category)

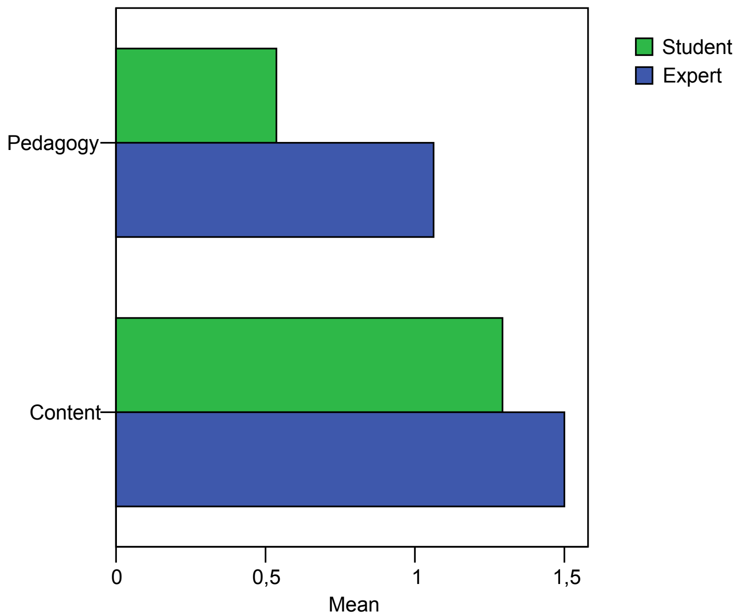


Figure 18. Energy conservation. Content "sum" and pedagogical "sum"

Total sums of content and pedagogy

In order to provide an overall image of the responses from the expert teachers and the trainees we have computed the total sums of content and pedagogy; see Figure 19.

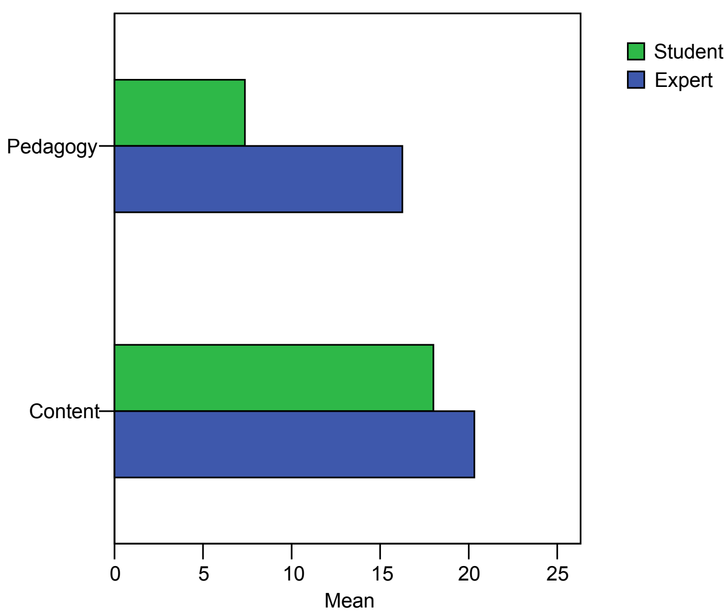


Figure 19. Total sums of content and pedagogy (Mann-Whitney U test: $p < 0.05$ for both)

As it has been seen through all the items in the questionnaire, what primarily characterises an expert teacher compared to the novices is that the expert more extensively uses pedagogical arguments in his or her responses. In average the experts have given 16,3 (std. deviation = 7,3) pedagogical arguments in total compared to 7,4 (std. deviation = 3,6) for the trainees. The spread in the sample distribution is relatively high for both groups.

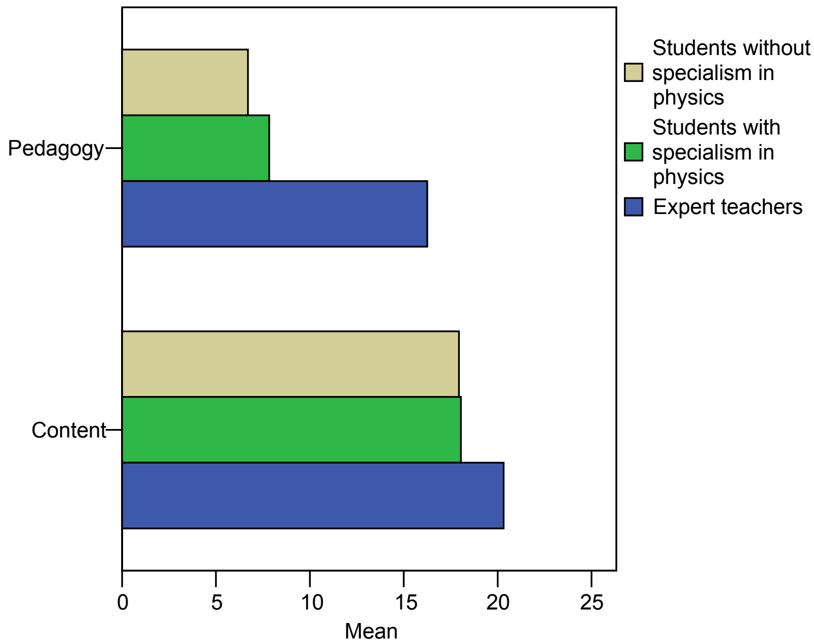


Figure 20. Total sums of content and pedagogy for the two student groups and expert teachers.

As mentioned in the introduction, we are also examining the trainee teachers without a subject specialism in physics alongside those of trainees with specialist physics backgrounds. However, these science graduates without background in physics have been through a six months extensive course in physics (the physics enhancement programme) preparing them for teaching physics up to and including A-level. There appeared to be very small differences between the two groups of students when looking at individual items and Figure 20 shows that the over all impression is the same. There are significant similarities between the two student groups for both content and pedagogy.

One might argue that a six months physics course is not enough to be a qualified physics teacher up to and including A-level in secondary school. However, the enhancement course was extraordinarily intensive, and one should be aware of that these students had graduated in other science subjects, and therefore they did not attend the course as novice students. So these students had both a strong motivation and a background within science which in addition to the enhancement course have contributed to making them competent to teach physics.

More about pedagogical knowledge

Figure 21 shows three aggregated variables from across the questionnaire. The category “logical sequencing” is found in five questions, “reference to alternative conceptions” in six questions and “reply with question(s) in three questions. The bars represent the percentage of those within each group who at least once have been coded into the category. For example 87 % of the experts and 39 % of the trainees have been coded for logical sequencing at least once. Moreover, six of the sixteen experts and only one student have been coded three, four or five times for logical sequencing.

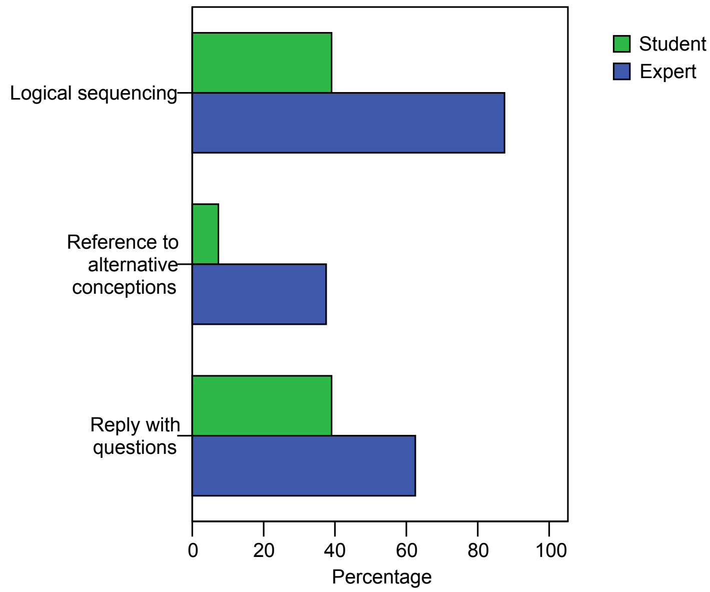


Figure 21. The figure shows the occurrence of three different categories from across the questionnaire (Mann-Whitney U test: *p* < 0.05 for all three categories).

Figure 21 also shows that very few of the students gave any references to alternative conceptions whilst 38 % of the experts did so. This is in accordance with Meyer (2004) who found that novice teachers hold limited conceptions of prior knowledge and its role in instruction while expert teachers hold a complex conception of prior knowledge and make use of their students' prior knowledge in significant ways. The difference between the experts and the trainees was not so salient for the variable "reply with questions"; however 62 % and 39 % respectively. The actual numbers behind the bars in Figure 21 are shown in the following tables.

			Group	
			Expert	Student
Reply with questions	0	Count	6	25
		% within Group	37,5%	61,0%
	1	Count	4	12
		% within Group	25,0%	29,3%
	2	Count	4	4
		% within Group	25,0%	9,8%
	3	Count	2	0
		% within Group	12,5%	,0%
Total		Count	16	41
		% within Group	100,0%	100,0%

Table 1. Reply with questions

			Group	
			Expert	Student
Reference to alternative conceptions	0	Count	10	38
		% within Group	62,5%	92,7%
	1	Count	5	3
		% within Group	31,3%	7,3%
	2	Count	1	0
		% within Group	6,3%	,0%
Total		Count	16	41
		% within Group	100,0%	100,0%

Table 2. Reference to alternative conceptions

			Group	
			Expert	Student
Logical sequencing	0	Count	2	25
		% within Group	12,5%	61,0%
	1	Count	4	9
		% within Group	25,0%	22,0%
	2	Count	4	6
		% within Group	25,0%	14,6%
	3	Count	2	0
		% within Group	12,5%	,0%
	4	Count	2	1
		% within Group	12,5%	2,4%
	5	Count	2	0
		% within Group	12,5%	,0%
Total		Count	16	41
		% within Group	100,0%	100,0%

Table 3. Logical sequencing

Table 4 shows the frequencies of suggested activities and/or productive discussions in class from across the questionnaire. The aggregated variable is made out of three individual variables. Most of the experts have one or more suggestions for activities or discussions in class when we look across the questionnaire whereas relatively few students made such suggestions.

			Group	
			Expert	Student
Suggesting activities and/or discussions	0	Count	2	16
		% within Group	12,5%	39,0%
	1	Count	4	21
		% within Group	25,0%	51,2%
	2	Count	9	3
		% within Group	56,3%	7,3%
	3	Count	1	1
		% within Group	6,3%	2,4%
Total		Count	16	41
		% within Group	100,0%	100,0%

Table 4. Frequencies of "suggested activities and/or productive discussions in class" from across the questionnaire

			Group	
			Expert	Student
Challenging student's response	0	Count	7	39
		% within Group	43,8%	95,1%
	1	Count	5	1
		% within Group	31,3%	2,4%
	2	Count	2	1
		% within Group	12,5%	2,4%
	3	Count	2	0
		% within Group	12,5%	,0%
Total		Count	16	41
		% within Group	100,0%	100,0%

Table 5. Frequencies of "analysis and/or challenge of students' responses" from across the questionnaire

Table 5 shows that there are nine expert teachers (56 %) but only two students (5 %) who have given answers categorised as "analysis and/or challenge of students' responses" if we look at this category across the questionnaire. Again we might conclude that experienced teachers use their pedagogical knowledge to a substantially greater extent than the novices do.

Conclusions

As already mentioned we are not claiming that our samples are statistical representative for all expert teachers and all trainees in the UK. For example; even though not all the experienced teachers in our sample possess all the characteristics of an expert, all the 16 experts seen together portray an image of what we can say is essential to be an expert teacher.

We have shown that expert teachers are more likely than novice teachers to refer to pedagogic issues in response to written questions about science content set in a school teaching context. Indeed, it is pedagogic reasoning, rather than conceptual understanding, that marks the difference between beginner and expert teachers in our sample. The following list is a summary of the ways in which expert teachers exhibited pedagogic reasoning in their responses:

- listing questions they would ask in the classroom;
- explicitly challenging a pupil's view;
- addressing pupils' everyday thinking;
- referring to pupils' prior learning experiences;
- suggesting possible class activities and/or discussions;
- suggesting teaching analogies that would help to explain the concept;
- providing a logical pedagogical sequence in their responses;

Our data reflect the difference between personal understanding of a topic and understanding what is required for someone else to know and understand it (Shulman, 2000). As already mentioned, the trainees' content knowledge and their understanding of the physics involved in the questions appeared to be quite good. However, the teachers also communicate a set of attitudes and values that influence pupils' understanding. This responsibility places special demands on teachers' own depth of understanding of the structure of the subject matter, as well as on teachers' attitudes towards and enthusiasm for what is being taught and learned.

But the key to distinguishing the knowledge base of teaching lies at the intersection of content and pedagogy, in the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogical powerful and yet adaptive to the variations in ability and background presented by the students. (Shulman, 1987).

Looking at the list above, the expert teacher is portrayed as having a wide range of knowledge. Moreover, the categories referred to also fit quite well into Shulman's "model of pedagogical reasoning and action". What actually characterises an expert teacher is how she or he can move from personal comprehension to preparing for the comprehension for others; how she or he is able to use multiple forms of representation, e.g. analogies, metaphors, activities, demonstrations etc.; how she or he makes links to pupils' preconceptions or misconceptions and other pupil characteristics.

Concerning the trainee teachers without a subject specialism in physics, our data show that there appeared to be very small differences between the two groups of students when looking at individual items and the over all impression is the same. There are significant similarities between the two student groups for both content and pedagogy. These students' understanding of the physics content presented in these questions did not appear to be influenced by the details of their physics/science education at university level. It appears that both student groups' lack of focus on pedagogy is a basic factor. The comparative analysis with expert teachers' responses has enabled us to identify in some detail the range of pedagogic understandings that these novice teachers will need to develop during their training. Our findings point to the need of creating new ways and opportunities for the development of pedagogical thinking among novice teachers. Indeed critical pedagogical reflection about teaching and learning has to be seen as an integral part of the teachers' professional development (Penso et al., 2001).

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Appendix

The Physics Enhancement Project
Pedagogical Content Knowledge (PCK) Probes

Coding scheme

Group	**Code**
Expert	1
Leeds PGCE	2
Keele PEP	3
St Martin (NW) PEP	4
St Martin (NW) not PEP	5
Keele not PEP	6

Gender	**Code**
Girl	1
Boy	2

Ball in the air v1a	**Code**
yes	1
No	2
almost, something	3

Ball in the air v1b (content)	**Variable** (code 1 if mentioned)
No statement of physics content	ba
(Constant) gravity, weight – only one force, resultant force	bb
Contact force (when throwing)	bc
Reference to momentum (correct)	bd1
Reference to momentum (not correct)	bd2
Relation/reference to change of velocity and/or acceleration	be
Air resistance (not correct). Resultant is zero on top (air resistance and gravity balance). Upward force and gravity balance at the peak.	bf
Reference to air resistance (correct)	bg
Relation/reference to energy (correct)	bh1
Relation/reference to energy (not correct)	bh2
General statements connecting force and motion	bj

Ball in the air v1c (pedagogical)	**Variable** (code 1 if mentioned)
No pedagogy	ca
Reply with question(s). Productive	cb1
Reply with question(s). Not productive	cb2
Some other pedagogical suggestion	cc
Logical sequencing	cd1
Anticipation of likely pupils' responses	ce
Reference to pupils' curriculum starting points	cf1
Making links to prior learning	cf2
Reference to everyday thinking (alternative conception)	cf3
Analysis and/or challenge of students' responses	cg

Skater v2a: force diagram	Variable
W (weight)	aa (code 1 if drawn)
R (friction, air resistance)	ab (code 1 if drawn)
N (normal force from the ice)	ac (code 1 if drawn)
F (pulling force)	ad (code 1 if drawn)
Number of forces (count friction and air resistance as 1)	ae (code numbers of arrows drawn)
Accurate position of arrows	af (code yes: 1; no: 2)
Accurate length of arrows	ag (code yes: 1; no: 2)

Skater v2b: force diagram (pedagogical)	Variable (code 1 if mentioned)
No vertical forces in order not to complicate the diagram for the pupils	ba
Some other pedagogical suggestions	bb

Skater v2c (content)	Variable (code 1 if mentioned)
No statement of physics content	ca
No pulling force (according to Newton's law).	cb
A pushing force when pushing off	cc
Reference to momentum (correct)	cd1
Reference to momentum (not correct)	cd2
Reasoning with/reference to energy (correct)	ce1
Reasoning with/reference to energy (not correct)	ce2
Only force is friction/air resistance and/or friction causes deceleration	cf
Unbalanced forces (pulling or pushing) cause acceleration/deceleration. General statement of unbalanced forces.	cg
Reference to a force in the direction of motion	ch

Skater v2d (pedagogical)	**Variable** (code 1 if mentioned)
No pedagogy	da
Reply with question(s). Productive	db1
Reply with question(s). Not productive	db2
	dc
Reference to another system/analogy	dd
Some other pedagogical suggestions	de
Logical sequencing	df1
Reference to pupils' curriculum starting points	dg1
Making links to prior learning	dg2
Reference to everyday thinking (alternative conception)	dg3
Analysis and/or challenge of student's response, e.g. what is the pulling force?	dh

In the dark v3a (content)	**Variable** (code 1 if mentioned)
Dark = no light, eye must receive light (correct physics)	aa
Misconception(s); e.g. ….	ab
Eyes adjust	ac

In the dark v3b (pedagogy)	**Variable** (code 1 if mentioned)
No pedagogy	ba
"Dark room" activity	bb
Reply with question(s). Productive	bc1
Reply with question(s). Not productive	bc2
Activities; e.g. look into eyes, deep sea fish, reflection, reflective coat, make black box. Productive	bd1
Activities; e.g. blindfold. Not productive	bd2
Discussion(s), talk about, explain; e.g. eyes, reflection (diagrams), caving exp., no light no vision, the cats eye. Productive	be1
Discussions, talks. Not productive	be2
The pedagogy is not addressing the issue.	bf
Analysis and/or challenge of students' responses	bg
Meaning of dark/difficult to get dark room and/or difference between scientific and everyday concept	bh
Logical sequencing	bi1
Anticipation of likely pupils' responses	bj
Reference to pupils' curriculum starting points	bk1
Making links to prior learning	bk2
Reference to everyday thinking (alternative conceptions)	bk3

Snowman v4a (content)	**Variable** (code 1 if mentioned)
Insulator (correct physics)	aa1
Reference to heat transfer, energy from hot to cold (correct physics)	aa2
Misconceptions; "keep the cold in". Snowman becomes warmer.	ab
Reference to the ambient temperature	ac
Irrelevant physics	ad

Snowman v4b (pupil responses)	**Variable**
No pupil response	ba (code 1 if mentioned)
Coat will make snowman melt, make warmth, keep warm	bb "
Keep the cold in	bc "
No difference, stay cold	bd "
Other relevant responses	be "
Number of relevant responses	bf (code number)
Reference to snowman is not "alive"/don't generate own heat	bg
Insulator contains warmth	bh

Snowman v4c (pedagogy)	**Variable** (code 1 if mentioned)
Suggestions to activities, discussions. Productive	ca1
Suggestions to activities, discussions. Not productive	ca2
Reference to everyday thinking (alternative conceptions)	cb

Electric charge v5	**Code**
v5a	1 – correct 2 – don't know 3 - incorrect
v5b	"
v5c	"
v5d	"
v5e	"
v5f	"

Series circuit v6a: key points (content)	**Variable** (code 1 if mentioned)
Energy (conservation)	aa1
Energy shared	aa2
Analogy; e.g. bread and vans, string	ab
Broken bulb breaks the circuit	ac
Increasing resistance, Total $R = R_1+R_2$	ad1
Decreasing current	ad2
Light will be dimmer	ad3
Same current in whole circuit. Current is not used up (in one bulb)	ae
Shared voltage	af1
Same voltage and/or same push	af2
Responses not related to key issue, e.g. "complete circuit"	ag
$U = RI$	ah
Incorrect physics	aj

Series circuit v6b (pedagogical)	
Logical sequencing	ba1
Reference to pupils' curriculum starting points	bb1
Making links to prior learning, e.g. simple circuit	bb2
Reference to everyday thinking (alternative conceptions)	bb3

Electrical analogy v7a: strengths (pedagogical)	**Variable** (code 1 if mentioned)
Movement of charge, charges not used up, constant flow	aa
Explain series and/or parallel	ac
Loss/gain of energy, energy transfer, conservation	ad
Relates to everyday experience	ae
Other valid responses	af1
Other not valid responses	af2
Simple to understand	ag1
Easy to visualise	ag2
Number of valid responses	ah
Separate charge from energy/charges carry eneregy	ai

Electrical analogy v7b: weaknesses (pedagogical)	**Variable** (code 1 if mentioned)
Energy is not a substance (to be delivered)	ba
Vans have self-contained energy source, no push from bakery/battery	bb
Doesn't explain resistance	bc
Vans slow down or stop at supermarket (he idea of constant current is lost)	bd
Doesn't explain voltage	be
Energy (also) back to bakery/battery (misconception)	bf
Cannot explain immediate changes in circuit	bg
Other valid responses	bh1
Other not valid responses	bh2
Can't explain parallel and/or series	bi
Number of valid responses	bj
Why is bread shared between the supermarkets	bk

Energy conservation v8a (content)	**Variable** (code 1 if mentioned)
Conserved – but not in useful forms, energy transfers/transforms/dissipates	aa
Energy resources are used up	ab
Other valid responses	ac1
Other not valid responses	ac2

Energy conservation v8b (pedagogical)	**Variable** (code 1 if mentioned)
Clarifying example(s) and/or some pedagogical suggestions. Productive	ba1
Clarifying example(s) and/or some pedagogical suggestions. Not productive	ba2
Other valid responses	bb1
Other not valid responses	bb2
Logical sequencing	bc1
Reference to pupils' curriculum starting points	bd
Making links to prior learning.	be1
Reference to everyday thinking (alternative conceptions)	be2