

**HOW CAN THE TOPIC OF ELECTRICITY BE
TAUGHT IN A WAY THAT ENGAGES YEAR 10
GIRLS WITH GCSE PHYSICS?**

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**A RESEARCH & DEVELOPMENT PROJECT
SUBMITTED FOR THE
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How can the topic of electricity be taught in a way that engages Year 10 girls with GCSE Physics?

Abstract

The aim of this action research project is to develop and teach a series of electricity lessons, using tasks which engage Year 10 GCSE physics students in a highly academic girls' school.

It builds on the work carried out in Part 2, where focus groups were carried out across four year groups to ascertain student perceptions of physics. Electricity was a topic perceived as particularly disengaging. The post-16 uptake of physics in my school is aligned with the national trend; the number of students choosing to study physics is significantly lower than the number choosing to take biology and chemistry. This study argues that increasing student engagement with electricity may be valuable to increasing the uptake of physics post-16.

This study begins with a literature review to set out what is meant by engagement, outlining the problems with the current research in the area and highlighting ways in which engagement can be increased. The use of modelling to increase engagement is thoroughly examined.

A survey of 144 Year 10 students was carried out to elicit students' views of engaging electricity teaching. Seven electricity intervention lessons were taught and their success was evaluated using Grounded theory to systematically analyse audio recordings from a Year 10 focus group of four students. Following the focus group, the intervention lessons were adapted to develop an electricity revision lesson for Year 11 students. The success of this lesson was similarly evaluated using a focus group followed by Grounded theory analysis.

The main findings of this study suggest that girls' engagement can be increased by ensuring that tasks are designed to include elements of synthesis of prior physics knowledge or opportunities for collaboration with peers. Girls were not engaged when tasks were perceived to have no relevance to their everyday experiences. Due to the level of abstraction inherent in much of the topic, it was found that the personal relevance of each task could not always be explicit.

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Research rationale

Personal rationale

During my part 2 project on: 'Discuss why so few girls study A-level physics and the factors affecting girls' choices to study physics post-16', a series of focus groups were carried out to ascertain the views of students across a range of year groups. From the focus groups, a general dislike for the topic of electricity was uncovered. The comments of two GCSE student had particular resonance with me:

Year 11, Student C: 'In physics, love space, hate electricity. It's harder to see in the every-day, it's harder to see where it links in.'

Year 10, Student D: 'you can't see what is happening in electricity, I don't understand it and I don't like not knowing what's going on.'

Sentiments such as those above are too common within the context of my school. This project seeks to develop a series of electricity intervention lessons which aim to eliminate comments such as these by making the topic more engaging to GCSE physics students. I want to promote physics and encourage all students in School A to engage fully with a subject for which I have great passion. However, my motivation isn't simply to increase engagement for its own sake. I would like all students in School A to develop a deep understanding of physics and furthermore to choose to continue with the subject at A-level and into higher education. I believe ensuring that they are engaged with the subject is fundamental to achieving this aim. Wang and Degol

(2014:136) state: 'student engagement is essential for successful learning' and higher levels of engagement lead to a greater number of students who: 'aspire to higher education' (2014:138). Similarly, Fredricks (2004:87) states that: 'engagement is associated with positive academic outcomes, including achievement and persistence in school'.

School Context

In School A, although the number of students who achieve highly in their GCSE examinations is equal across the three sciences, 94% A* or A-grade, the number of students who choose to study biology and chemistry post-16 is approximately three times larger than the number who choose to continue with physics. The problem of few girls choosing to study physics post-16 is not unique to School A. Daly, Grant, and Bultitude (2009:iv) discuss a national problem in the UK where girls make: 'a conscious choice not to study physics even though they have the ability to succeed in the subject'. They note the problem that 'a substantial number of girls do well at Key Stage 4 but do not choose to study physics post-16' (2009:iv). Unfortunately, this is the case at School A. It would seem that high academic achievement at GCSE does not result in increased A-level uptake. I believe that increasing student engagement with physics plays a crucial role in solving this problem in School A. The topic of electricity has been chosen as a focus because it is a large topic in all three Key Stages and the students in School A have consistently ranked it as their least favoured topic in physics.

International Context

The problem of fewer girls choosing to study A-level physics is an incredibly topical issue at present, both in the UK and abroad. Archer et al (2013:1) note that: ‘many governments and organisations are concerned that not enough young people are choosing to study Science, Technology, Engineering and Mathematics (STEM)’. It is predicted that this may have a negative economic impact on the UK economy. In a report by President’s Council of Advisors on Science and Technology¹ it was stated that:

‘The United States cannot remain at the forefront of science and technology if the majority of its students—in particular, women ... [are] underrepresented in STEM fields—view science and technology as uninteresting...’ (2011:17)

Engagement

Defining engagement

The current literature on engagement is quite fragmented, stemming from the diverse range of psychological theories used to examine it. Fredricks (2016:1) notes that some authors have borrowed constructs from: ‘motivational theories such as self-determination, self-regulation, flow, goal theory, and expectancy-value’. The wide variation in the way in which student engagement has been defined and studied has resulted in different research groups using a variety of working definitions of, and

¹ <https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/pcast-stem-ed-final.pdf> [Accessed 26th July 2017]

instruments to measure student engagement. The operationalization of the dimensions of student engagement is also inconsistent. Fredricks argues that researchers have not engaged in critical analysis of the construct definitions and theoretical frameworks of prior work before selecting them for their research.

In a special issue paper devoted to defining and measuring engagement, Azevedo (2015:84) notes that: 'Engagement is one of the most widely misused and over-generalized constructs found in the educational, learning, instructional and psychological sciences.'

Fredricks (2016:2) argues that there is a concern that: 'by defining engagement so broadly the field runs the risk of explaining almost everything related to students' experiences in school and as a result not really explaining anything at all.' Boekaerts believes the academic community: 'need[s] to identify the crucial elements of engagement processes and separate them from peripheral aspects that have been introduced into engagement literature over the years' (2016:81).

In the years succeeding the seminal paper by Fredricks et al (2004), there has been some agreement in the literature that engagement is a multidimensional construct (Eccles (2016), Fredricks et al (2016), Jang, Kim and Reeve (2016), Jarvella et al (2016), Salmena-Aro et al (2016), Shernoff et al (2016), Wang et al (2016)). However, there is not universal agreement, as other authors such as Sinatra, Heddy and Lombardi (2015:8) suggest an approach which places engagement on a continuum. In addition to the three widely accepted types of engagement that will be discussed, many authors have proposed the addition of a fourth dimension to engagement. Fredricks et al

(2016) and Wang et al (2016:17) define a social dimension which includes: 'the quality of social interactions with peers and adults, as well as the willingness to invest in the formation and maintenance of relationships while learning. Jang, Kim and Reeve (2016:29) defines agentic engagement as 'initiating action to render one's environment more supportive and need satisfying'. Jarvella et al (2016:40) use constructs from self-regulation theory to incorporate interactions with the context. They define self-regulation learning engagement as: 'the extent to which individuals think strategically, before, during, and after the performance of some learning activity.'

In a recent study, Wang et al (2016) have found psychometrically sound evidence using a bifactor model approach to suggest that there are four fundamentally distinct, yet related, dimensions of student engagement: Behavioral, emotional, cognitive and social engagement. The data found evidence to support predictive validity and measurement invariance. Their emphasis on social interactions in the classroom is not universally accepted in the literature. They used a mixed methods research design to develop a student-report survey comprised of 33 items on student engagement, answered on a 5-point Likert scale by 3883 high school students, from 6th to 12th grade. In addition, 300 students were then selected randomly to be rated by their teachers, on their engagement using a 20-question survey, answered on a 5-point Likert scale by 130 teachers.

Wang et al (2016) argue that their study makes a unique contribution to the literature as the first to use a validated self-report measure to characterise mathematics and

science engagement with four distinct dimensions with a global engagement construct. There are few studies which measure engagement in specific subject areas and even fewer that investigate the individual contribution of each dimension on engagement. However, Boekaerts (2016:77) questions whether the addition of teachers into this study can add to the theory of engagement as the observations of students by their teachers can be incomplete, biased and potentially clustered.

There is disagreement in the literature as to whether engagement and disengagement should be viewed on a continuum or whether they should be viewed as empirically distinct constructs (Salmena-Aro et al (2016:62)). However, Jang, Kim and Reeve (2016:29) describe current research in this area as 'sparse and largely not yet undertaken'. However, for this study engagement and disengagement will be treated as a continuum as this is more common in the literature.

One of the issues that arises from having such a broad construct of engagement is that it is difficult to compare the findings of different research groups as the items in the methodologies used to measure behavioral, emotional and cognitive dimensions have been used inconsistently. For example, Wang et al (2016:17) notes that some researchers use effort as an indicator of cognitive engagement, describing the level of psychological investment in learning, while others use it as an indicator of behavioral engagement to reflect compliance with required work in school.

As a universally accepted definition of engagement is not present in the literature, the most prevalent definition of engagement will be used in this dissertation. It is a

tripartite engagement framework comprised of: Behavioral, emotional and cognitive dimensions. In their literature review of engagement, Fredricks et al (2004:2), define engagement with the following multidimensional construct:

Behavioral engagement: 'draws on the idea of participation; it includes involvement in academic and social or extracurricular activities and is considered crucial for achieving positive academic outcomes and preventing dropping out.'

Emotional engagement encompasses: 'positive and negative reactions to teachers, classmates, academics, and school and is presumed to create ties to an institution and influence willingness to do work.'

Cognitive engagement: 'draws on the idea of investment; it incorporates thoughtfulness and willingness to exert the effort necessary to comprehend complex ideas and master difficult skills.'

When measuring engagement, self-reports are the most common instrument used in both individual and group contexts. However, there are few researchers who use psychometrically valid measures of assessment which view engagement as a multidimensional construct. In addition, Fredricks (2016:2) argues that more needs to be done by researchers to incorporate and measure the variation of engagement across activities and longer-term engagement; additional quantitative and qualitative methodologies are required.

What is the distinction from motivation?

It is assumed by most researchers that engagement and motivation, although related, are separate constructs. Boekaerts (2016:76) states that motivation and engagement differ in that motivation is unobservable and internal in nature whereas engagement is a publically observable behaviour.

However, owing to the broad definition of engagement, there is often an overlap between engagement and motivational constructs (Fredricks 2016:2). For example, behavioral engagement often includes motivational constructs such as persistence and effort (Sinatra, Heddy and Lombardi (2015:3)). Although motivation cannot be characterised as another dimension of engagement, it can be said that motivational constructs run through each dimension of engagement, both implicitly or explicitly (Sinatra, Heddy and Lombardi (2015:2)). Boekaerts (2016:81) states that although motivation is: 'implicated in engagement', it is not at its core.

Sinatra, Heddy and Lombardi (2015:4) note a current problem in the literature is a risk of researchers conflating: 'cognitive engagement with existing motivational or self-regulatory constructs already widely used in the literature.' More needs to be done to disentangle the key components of motivation and engagement, using integrative approaches. Boekaerts (2016:83) believes that an international task force should form and hold a consensus-building conference on the meaning of engagement and its boundaries.

Why is engagement an important concept?

Although increased engagement has been attributed to improving educational outcomes in a broad range of educational, learning, instructional and psychological sciences, this should not undermine the impact that increased engagement can have in the sphere of education. Researchers have consistently posited that increased engagement can be linked to long term involvement in schooling and positive learning outcomes both in and out of school. However, it is quite troubling that at present there is no universally accepted definition.

Sinatra, Heddy and Lombardi (2015:1) describe engagement as ‘the holy grail of learning’. Boekaerts (2016:76) argues that: ‘Comprehension of the motivational, cognitive and emotional aspects of engagement and disengagement is undeniably one of the most crucial goals of educational psychology, because it has theoretical as well as far-reaching practical implications.’

Models

Defining models

Within the literature, the term ‘model’ has been described by authors in subtly different ways, the most prominent of which have been outlined below. There are multiple subgroups of models, the most extensively defined of which is the ‘mental’ model. However, for completeness, other prominent models, with relevance to teaching and learning practices, include: ‘conceptual’, ‘expressed’ with a subset

termed 'consensus', and finally 'instructional' or 'teaching' models. Each usage of the term model is compatible with a Vygotskian constructivist view that knowledge building takes place within the mind of the individual as well as collectively in society.

Ingham and Gilbert (1991) describe a model as a simplified representation of a system, with a specific focus on certain aspects of that system. Gilbert (1995) states that models either allow complex aspects of a system to be made visible or allow aspects of that system, which are of scales that are not normally visible, to be made more readily visible.

More specifically, Harrison and Treagust (2000) describe 'scientific' models as simplified or abstract representations of systems or phenomena, which allow the key aspects of that system to be made visible and explicit. Hence, explanations and predictions can be made about that system or those phenomena.

Johnson-Laird (1983) states that 'mental' models are an individual's internal cognitive representation of a system which they construct and reason with to support understanding through the simulation of the behaviour of a system in the real world. The idea of a mental model is developed further by Renk, Granch and Chang (1993), who state that mental models are domain specific, explanatory and predictive representations created and existing in the mind as a description of a system, theory or phenomenon. Vosniadou (2002) suggests that mental models are able to generate predictions and explanations through their ability to be explored extensively in the 'mind's eye'. Vosniadou (2002) posits that they are generated when people are faced with truly novel situations that they can't understand on the basis of prior or easily

deduced information. Vosniadou (2002) states that they are an intermediate step which allows implicit physical knowledge to be conceptualised to aid theory construction. This Piagetian view of the use of mental models in active knowledge construction is also shared by Laird (1983:10): 'human beings understand the world by constructing models of it in their minds'. Where mental models facilitate the assimilation and accommodation of novel situations into the students' cognitive structures.

Although the literature reveals relatively diverse descriptions of mental models, a common theme is that they are 'internal cognitive representations of complex or inaccessible phenomena that can run in the mind to generate predictions or explanations of the phenomena' Williams (2011:9).

Mayer (1989) describes 'conceptual' models as words and/or diagrams that are intended to aid students in building mental models of a target system. Mayer conducted research into the use of conceptual models in science over a 15-year period. Positive student outcomes in terms of increased recall of conceptual information and increased problem-solving abilities as well as a decrease in recalling information in verbatim form were reported in all cases.

(Gobert and Buckley, 2000) describe 'expressed' models as being external and material, for example, using written descriptions, actions and speech. The sub group of 'consensus' models are those material depictions which have resulted from a social

construction through development, testing and agreement by a group of experts or learners.

Finally, Williams (2011) describes 'instructional' or 'teaching' models, which teachers and curriculum developers use to facilitate the understanding of a particular concept. They utilise equations, diagrams, computer simulations, apparatus and physical three-dimensional objects in order to represent situations or phenomena that they would otherwise be unable to represent accurately in the classroom. However, Davis et al (2008:19) argue that there is need for a fundamental change in the way in which teachers use models in the classroom. Instead of viewing models as a stand-alone representation for the teaching of known scientific facts and how systems behave, more should be done to promote teachers to encourage their students to evaluate and revise them. This will allow students to better explain and predict phenomena.

Using model-based teaching to increase student engagement

Williams' (2011) medium scale study of 14-18-year-old secondary school physics students indicated that students who studied a six-eight week long electric circuits course through model-based instruction reported significantly increased levels of engagement, compared with students taught with 'traditional' methods. The CASTLE (Capacitor Aided System for teaching and Learning Electricity) (Steinberg (2004)) curriculum was taught to an intervention group using model based teaching strategies, using an iterative OGEM (Observation, Model Generation, Model Evaluation and Model Modification) cycle (Williams (2011:114)).

A mixed method approach was used, comprised of a 33-item, pre-and post-intervention self-report survey of over 500 students from 27 different classes. In addition, post-intervention student interviews with a small number of students were carried out; the exact number isn't shared in the study. The number and gender of the students from both groups was approximately equal; the study found no significant difference in response by gender.

However, the analysis of the survey results does not make explicit which dimension or dimensions of engagement the survey results are being measured against. From the self-report surveys, the following questions, all of which have been reported to have shown significantly greater positive responses from the intervention group, could be viewed as measures of student engagement:

Question 11: 'While learning about electricity in this unit, I found that I revised or updated my ideas about electricity' Williams (2011:181).

Question 15: 'During the electricity unit, I explained my ideas in whole class discussion' Williams (2011:183).

Question 16: 'During the electricity unit, I contributed my ideas on small group discussions' Williams (2011:183).

Question 17: 'During the electricity unit, other students explained their ideas to me' Williams (2011:184).

Question 11 can be seen as a measure of cognitive engagement, whereas the other questions could be viewed as measures of emotional engagement, although as previously stated, it is unclear whether the author has coded them in this way.

Incorporating analogies into model-based teaching of electricity

Collins and Gentner (1987) posit that through the process of partitioning, analogies can be used to facilitate the construction of students' mental models. Partitioning involves constructing a chronology of the evolution of the state or phase of a physical event that is familiar to the student. Through this process students can model the complete evolution of the state or phase of the physical event. However, if a student is unable to imagine all possible states or phases of a physical event, due to the physical event being unfamiliar, analogical mappings are required. An analogical map allows the known chronology of events, the bases, into the new domain, the target. Thus, students can construct mental models in order to make inferences in the target domain.

Stocklmayer and Treagust (1996) outline five analogies that are commonly used to facilitate the generation of students' mental models when studying electricity: the train analogy, the 'gravitational analogy', the water analogy, the moving crown analogy and the anthropomorphic analogy. A common theme running through all five analogies is the portrayal of electricity as the flow of an energy-carrying object or particle around a closed loop. An adaptation of the latter four analogies has been used in this M.Sc., a copy of which can be found in Appendix 1. However, Shipstone (1988)

notes that many students are unable to draw links between analogies of circuit phenomena and the quantitative mathematical description of those same circuit phenomena. As is the case with model-based teaching of electricity, students should be given adequate time to develop a deeper understanding of the concepts being illustrated by the analogies.

Toward instruction for model-based teaching of electricity

It is clear from the literature that models can function as an important tool within science education. Hestenes (1987), an exponent of model-centred instructional design highlights the importance of developing a coherent theory in order to improve instructional practices in physics teaching. Although, there is currently no coherent theory to describe either the cognition involved in model-based learning or the best approach to model-based teaching, this section will attempt to provide instruction for how best to use models to improve the teaching of electricity.

By their very nature, the concepts studied in an electricity course are inherently abstract and intangible. A model-based approach to teaching electricity encourages students to focus initially on the underlying nature of the key elements involved in the functioning of an electrical circuit: charge, current, potential difference and resistance.

Hestenes (1987) suggests that it is crucial that an adequate amount of time is dedicated to the initial stage of modelling; the generation of a complete set of

descriptive variables. Hestenes (1987) argues that too often, there is an early focus on the use of mathematical equations and partially developed analogies to find the solution to a problem which they are not adequately equipped to understand. Eylon and Ganiel (1990) revealed that most 17-18-year-old student in a study of high school students' ideas of electricity could not understand the link between the behaviour of charge at a microscopic level and the subsequent behaviour of circuit devices at a macroscopic level. This is because students are frequently provided with inadequate physical mechanisms or models to explain circuit principles, thus allowing pre-existing misconceptions to persist. It is important that teachers provide adequate models to ensure that students are able to draw links both levels.

Licht (1991) supports this idea by arguing that there should not be an initial emphasis on the mathematical quantification of circuit phenomena and on memorising scientific terminology. Licht (1991) goes on to state that initially, students would benefit from being assigned more time to develop a deeper understanding of the concepts within their working mental models, through a practical approach. This develops the students' cognitive abilities, enabling them to draw links between macroscopic and microscopic domains present in electricity.

Larkin and Chabay (1989) argue that the issue of a lack of conceptual understanding about the way in which a circuit functions is exacerbated by the extensive use of schematic diagrams within teaching and learning strategies. They are intended to provide students with a picture of the workings of an electric circuit, but instead provide very little insight into the cause of the circuit phenomena they are told to

investigate. Schematic diagrams are typically accompanied by a problem, which they are taught to solve using an entirely mathematical approach. For example, selecting Ohm's Law, rearranging it algebraically, selecting and imputing the numerical values of each variable. Finally, a numerical answer is obtained without the student necessarily having any conceptual understanding of the problem. Clearly, students would benefit from an approach to teaching electricity which leaves the mathematical formulation until after charge, current, potential difference and resistance are more fully developed through modelling.

Due to students' difficulties in understanding more abstract terms, Wellington and Osborne (2001) state that, 'the more abstract a term becomes the more it must be taught by analogy or by the use of models' (P23). In addition to the use of models they note that teachers should be sensitive to misunderstandings when students are acquiring new vocabulary and that teaching time needs to be devoted to discussing and explaining the meaning of scientific terminology. They argue that the meaning of scientific vocabulary must be explicitly taught as misunderstandings with language are incredibly difficult to address at a later stage.

To conclude the use of modelling when teaching electricity, Williams (2011:47) states that providing students with multiple models when studying electricity significantly increases their problem-solving capabilities, compared to students who have only been provided with one model. This has been shown to have a greater effect for students who are required to integrate multiple models of the same concept, as stronger connections between the mechanisms and representations of these models

are generated. Although, Mayer (1989) notes that high ability students do not benefit from being presented with multiple models. Mayer posits that this group of students are more likely to either enter the class with pre-existing models or the ability to rapidly construct them from the lesson without assistance.

What do students find difficult when learning about electrical circuits?

There are two main difficulties associated with the understanding of electrical circuits. The first relates to inherent difficulties students encounter when trying to conventionalise the phenomena that the topic encompasses. The second is the inherent difficulty students find in understanding the terminology associated with electricity.

In traditional teaching methods, students are initially taught the behaviour of simple circuits, consisting of: wires, cells, bulbs and resistors. Students find it notoriously difficult to conceptualise the underlying cause of potential differences between different positions around a circuit and the flow of charge that results from these potential differences (Cohen, Eylon and Ganiel (1983) and Fredette and Clement (1981).

Within the literature there are many well documented and widespread misconceptions that prohibit the development of a deeper understanding of the functioning of electrical circuits at GCSE. Driver et al (1994) outline a misconception, pertinent to the students featured in this M.Sc. study, as they persist into GCSE age

students. This is the misconception that current is used up as it passes through a component. Driver et al (1994) attribute this deep-seated misconception to the everyday experience of cause and effect. Students assume that as a result of a current passing through a component, there has to be a resulting effect on the current.

Wellington and Osborne (2001) argue that semantics plays a vital in knowledge acquisition in science education. Using a taxonomy of words, first proposed by Wellington (1982), scientific words can be categorised into four discrete levels: naming, process, concept and mathematical words.

As concept words are the most relevant to teaching electricity, this level will be further elucidated. Wellington and Osborne (2001) argue that concept words are particularly difficult for students to assign meaning to because their understanding depends upon prior understanding of other words. Concept words which have an everyday meaning as well as a scientific meaning, such as 'charge' and 'resistance', present difficulty because students are required to create new or different meanings for these words.

Meyerson et al (1991) identified a particular difficulty with students' abilities to identify words with both scientific and everyday meanings. In their study, they examined the knowledge of science vocabulary of 267 8-9 and 10-11-year-olds. The students were given a worksheet which assessed their understanding of each word by placing them into different conceptual groupings. Follow up interviews were conducted to ensure that their responses could be understood by future evaluators. A list of the most commonly occurring technical words was constructed using five popular science text books and two vocabulary lists relevant was compiled. However,

the 8-9-year-old and 10-11-year-old groups were presented with 15 and 26 words respectively, so their findings are of questionable significance.

Concept words which are particularly abstract, unobservable and belong to theoretical constructs, such as 'current' and 'potential difference', present the most difficulty.

These words only have meaning when they are in theoretical context, they lack meaning to students as they have no visual or physical referent. Stockmayer and Treagust (1996) suggest that students have a limited understanding of, among other words, 'current' and 'potential difference'. A study by Farrell and Ventura (1998) supports this, when comparing the disparity between the claimed and actual ability of 187, 17-18-year-old students from an advanced-level physics course, they found that although 98% of students claimed to be able to define 'current', only 44% were actually able to provide a definition. Their study was to assess the students' comprehension of the 50 and 25 most frequently used non-technical and technical words respectively, in the Physics A-level course. 'Current' is the only technical word pertaining to electricity that appears in their study as words such as 'charge' did not occur often enough in the A-level course to be included in their list of 25 most frequent words. Additionally, Maichle (1981) and Rhoneck (1981) have found that there is a strong tendency for students to consider the properties of current and potential difference as incredibly similar. Rumelhart (1983) suggests a reason for students' difficulties in comprehending more abstract words is that they don't have a pre-existing schema in which to incorporate this new abstract knowledge.

Girls as learners

Murphy and Whitelegg (2006) argue that girls view learning and knowledge acquisition in a fundamentally different way from boys. Girls relate their academic interests to their everyday life, concerns and personal interests, valuing the circumstances in which tasks are set and not valuing issues which are abstracted from their context. Human aspects such as learning to help others is linked with the purpose of knowledge acquisition. This is supported by Stadler, Duit and Benke (2000) who argue that understanding is different for girls; they need to put something into a broader context first in order to say they understand it, as learning is located between the world and the system.

Smithers and Hill (1987) describe girls as more person-orientated, cooperative and socially responsible than boys. Although this characterisation of girls is used throughout the literature, it should be noted that in a recent quantitative analysis of surveys of over 12000 13- and 15-year old students in the UK, Mujtaba and Reiss (2016:79) have found evidence that goes against the general suggestion that girls are generally more cooperative than boys. Their data found that girls with high mathematics aspirations post-16 have a tendency to veer more towards self-enhancement as opposed to group enhancement, indicated by their findings that this group was the most competitive, more so than the most academically successful boys. Mujtaba and Reiss suggest that a cause could be that the current educational and classroom environment in the UK is more competitive than in previous decades.

Kearney (1993), Murphy and Whitelegg (2006) and Stewart (1998), argue that there is a problem with the curriculum itself. As girls value the circumstances in which tasks are set, they find it difficult to make sense of physics and its purpose. Mujtaba and Reiss (2013a) argue that girls prefer courses that are person-orientated and that the lifestyles associated with STEM are unattractive due to the perception that scientists have little relevance to social problems. Baker and Leary (1995) notes that a curriculum that has a strong affective component and relevant topics that address girls' concerns such as saving the Earth, helping animals and helping people, is another way of enhancing girls' engagement.

Doyle (2015) does not seem to believe that with the current climate of politicisation of education and subsequent focus on examination results, teachers are allowed the freedom to address to the problems that the previous literature has outlined. Doyle states: 'high stakes government accountability systems narrow curriculum precisely because they typically constrain the range of tasks that are perceived to be appropriate for classrooms.' (2015:xiv).

General task design

In addition to techniques specific to increasing engagement in electricity, it is important that the aim of the task design in general is to increase engagement. Thompson (2015:3) states: 'Engaging students in learning about their subject is a central concern for all teachers and teacher educators. The issue of task design in secondary education, how teachers view and use the pedagogic potential of different

tasks to engage pupils with knowledge in different subjects, is central to this endeavour.'

Doyle (2015) reaffirms this idea when stating: 'The tasks a teacher defines for a lesson or unit shape how pupils engage intellectually with the content of the curriculum'.

Within the literature, the term 'task' is often used interchangeably with the term 'activity'. Some academics draw a distinction between these terms. For example, Elkonin (1999:5) defines 'learning activities' as 'that activity by which the child acquires new knowledge and for which a system of instruction should provide proper guidance' and 'tasks', as 'action[s] or operation[s]' Elkonin (1999:6). However, for the purposes of this dissertation, the term 'task' will serve a wider function of incorporating not only specific actions or operations but everything else that a student is doing to reach the desired learning outcome and the term 'activity' will not be used.

It is important that activities allow students the opportunity to draw links between what they are participating in within the classroom and everyday situations which are familiar to them. Barnes (1976:29) argues that: 'Many of the tasks set in schools do not make it easy for pupils to utilize their everyday knowledge'. Doyle (2015:xiv) supports this statement: 'students are not "learners" in some disembodied, abstract sense'. It is important that students find personal relevance in the activities that they participate in.

Methodology

Year 10 intervention

In this action research study, a series of activities were designed to teach the topic of electricity in a way that increased the students' emotional and cognitive engagement; behavioral engagement is not a concern in the selective grammar school context of School A. The school studies the AQA (2016) GCSE Physics (8463) specification and as such there are constraints on the intervention in terms of the content that can be taught and the timeframe in which this material can be taught; preference has not been given to this topic to the detriment of other areas of the specification. The topic areas that are included in this intervention are as follows:

- 1) Standard circuit diagram symbols, totalling 14 circuit symbols.
- 2) Word and mathematical definitions of electrical charge, current, potential difference and resistance, including appropriate units.
- 3) Series and parallel circuits, including explanations and calculations involving: current; potential difference and resistance in series circuits and current and potential difference in parallel circuits. Both types of circuits contain: wires, bulbs, fixed resistors, ammeters and voltmeters.
- 4) Required practical activity 3: use circuit diagrams to set up and check appropriate circuits to investigate the factors affecting the resistance of electrical circuits. Including the length of wire at constant temperature and combinations of resistors in series and parallel.

The electricity topic was studied by 25 students from a Year 10 class during January and February of the Spring term. The intervention was carried out during the first seven lessons of this topic, totalling seven hours of lesson time. Subsequent specification content such as power and energy transfer have not been included in this intervention. Although not explicitly stated in the lesson sequences outlined below, each task and lesson was designed and taught with an appreciation of a constructivist Vygotskian theoretical perspective. The affective and cognitive domains are considered equally important in this intervention. It is also of note that tasks devoted to increasing self-efficacy are not relevant to the students in School A. It was made explicitly clear during focus groups in the Part 2 study that the students in School A do not report to have gendered views pertaining to any task or subject and as such they believe they can achieve highly in their physics GCSE.

Lesson Sequence

Lesson One: Task sequence

The starter task for this lesson instructed the class to: 'Write down in the back of your books everything you have done today'. Later, the class were told to 'Highlight everything that involves electricity'.

The main task split the class into five equal groups and each student was given the same copy of one of the following analogies, adapted from Stocklmayer and Treagust (1996): The 'rope loop'; 'water flowing in a pipe'; 'gravitational potential'; 'crowded room' and the 'bath', copies of which can be found in Appendix 1. The group had ten

minutes to read through their particular analogy and decide upon how they were going to explain it to other students. Five new groups were then formed so that each new group contained one student from each of the original groups, who was considered 'the expert' on one of the five analogies. Each group then had fifteen minutes in which each 'expert' would explain their analogy to the rest of the group. A sixth 'band saw' analogy was provided as an extension.

At the end of the lesson, the class filled in a brief questionnaire answering two questions:

- 1) Which of the analogies was your favorite?
- 2) Which of the analogies was your least favorite?

The analogies provided visual representations in five different physical situations. The first four stated below are representations for series circuits only. The 'rope loop' provided an analogy to understand current, charge and resistance. The 'water flowing in a pipe' analogy provided a representation of potential difference, current and resistance. The 'gravitational potential' analogy provided visualisations of potential difference, resistance and charge. The 'crowded room' provided a visualisation of resistance, potential difference and temperature. The bath analogy provided a representation of resistance and current in parallel circuits.

Theoretical rationale: Lesson One

The lesson began with a task designed to enable students to find personal relevance in the topic of electricity, as many authors have suggested that girls value activities which are linked to real-world situations (Baker (1995), Mujtaba and Reiss (2013a), Murphy and Whitelegg (2006) and Smithers and Hill (1987)). A collaborative element to tasks has been proposed by numerous authors, many of whom cite Smithers and Hill (1987) as the origin of the notion that girls are more collaborative than boys.

The use of analogies in the main task was intended to allow the students an early opportunity to develop their own mental models of current and potential difference in simple circuits. Collins and Gentner (1987) suggest using analogies as an effective way to allow students to generate mental models, with Hestenes (1987) and Licht (1991) emphasising the importance of introducing mental models at an early stage of electricity study. Integrating multiple mental models has been suggested by Williams (2011) to increase problem solving capabilities.

Lessons two and three: Task sequence

The second and third lessons exclusively used the Explore Learning website². During these lessons, the class worked in groups of two or three to build series and parallel circuits using the online simulations.

² <https://www.explorelearning.com> [Accessed 9 September 2017]

In the second lesson, the main task comprised of building 13 circuits, with three extension activities. Screenshots of the circuits were provided on a handout (see Appendix 2) and the current and potential difference was recorded at various places around the circuits on a separate handout. The circuits contained: wires; bulbs; cells; ammeters and voltmeters. The plenary involved commenting, without using the simulation, on the current and potential difference in two pairs of circuits.

During the third lesson, fixed resistors were introduced into the simulations. For the first task, the class used screenshots on a handout to build six additional circuits. The class measured the resistance at various places around the circuits using simulated ohmmeters, recording them on a separate handout as before; two extension circuits were also provided.

The second task investigated the relationship between current and potential difference as fixed resistors were added to a circuit in series, the simulation did not provide a variable resistor. The potential difference across the resistor network and the current through it was measured and recorded.

The third task investigated Ohm's law; the potential difference of the cell in a series circuit is increased while the resistance was kept constant. The current through the resistor was measured and the values were subsequently used to plot an I-V graph. This procedure was repeated for two other fixed resistors.

The plenary invited the students to use the knowledge gained from lessons two and three to comment on the potential difference across and the current through individual branches of three screenshots of parallel circuits. Homework was set for the next lesson: the students had to commit 14 circuit symbols and six physical quantities to memory (charge, potential difference, resistance, energy, current and time); this included their units and the mathematical symbol (seen Appendix 3).

Theoretical rationale: Lessons two and three

One of the key findings from the Part 2 study, in relation to students' views towards the topic of electricity, was that students found building electrical circuits frustrating as they were frequently unable to build circuits effectively in order to take appropriate readings. By presenting students with simulated circuits initially, a potential cause for frustration and ensuing disengagement was removed.

In order to aid students' conceptual understanding of the way in which circuits function, the Explore Learning simulations allowed a way to prevent schematic representations from being introduced at this stage of the course. Larkin and Chabay (1989) have found that schematic representations do not provide students with an insight into the cause of the circuit phenomena.

It was assumed that allowing students to first take measurements from a simulation which closely resembled the real-world system would facilitate the construction of students' mental models as it would remove a level of abstraction. It should be noted

that Mejia (1994) found no difference in engagement or other positive learning outcomes when using concrete visual representations over abstract representations. However, this study was carried out on university students with an average age of 22, by this age they have more established mental models to describe a circuits functions.

Finally, the plenary task allowed students to draw their own conclusions from the phenomena they had been instructed to observe. Although the previous tasks in the lesson could be viewed as being highly scripted, in a study of four Year-10 students' experiences of structured and non-structured tasks in electricity, Pathak et al (2011) found that over scripting can be detrimental to meaning making. Therefore, the students were given a less structured task to help them to make meaning for themselves.

Lesson Four: Task sequence

The starter task was a peer assessed quiz on the previous lesson's homework. The class had to recall the name of a component from the associated circuit symbol or the converse. In addition, each student had to complete a table to show they could recall the unit and mathematical symbol used for the six aforementioned quantities.

The second task involved the class answering the question: 'How does energy come from a lump of coal to your [mobile] phone?'. The class were allowed to work in groups of three or four and given A3 sugar paper and after a few minutes, pictures of

coal, fire, power station, turbine, electricity pylons and an iPhone were projected onto the smartboard.

The main task gave ten pairs of 'true or false' statements about 'charge', 'current', 'potential difference', 'resistance' and 'energy' (see Appendix 4). Each student had to hold up a whiteboard to indicate which of the statements was correct and each statement was then discussed.

The final task involved using a teacher lead PowerPoint presentation and two simulations from the PhET website³: 'Balloon and Static electricity' and 'Ohms Law' to describe charge and resistance respectively. Students were given printed notes to accompany the descriptions. As time had not previously allowed for a review of the tables of data, recorded during lesson one and lesson two, the final task gave students the opportunity to self-assess the data.

Theoretical rationale: Lesson Four

The main function of the fourth lesson was to consolidate the material that had been taught in the previous three lessons and to start to introduce the students to more formal definitions of current and potential difference. The first task did not employ any nuanced teaching strategies. The students were expected to use any methods familiar to them to memorise the given information, for example, rote learning. Licht

³ <https://phet.colorado.edu> [Accessed 9 September 2017]

(1991) suggests that the memorising of scientific terminology should not be introduced until students have a deeper understanding of the phenomena within their working mental models, therefore memorisation was introduced at this stage.

The purpose of the second task was twofold. The first was an admittedly crude attempt to assign personal relevance to the lesson, in much the same way as the starter task from lesson one. The second function was to allow the students to link some of the terminology that had been learnt over the previous lessons, to the topic on 'the national grid', which had been learnt in Year 9.

The main task also aimed to consolidate the terms 'charge', 'current', 'potential difference', 'resistance' and 'energy', whilst at the same time using a common AFL technique.

The 'Balloon and Static electricity' PhET simulation sought to teach the term 'charge' by using a concrete visual representation that would be familiar to the students. The 'Ohms Law' simulation provided the students with a concrete visual representation of a wire to provide a mental model which would allow students to understand the link between microscopic and macroscopic phenomena which is required to understand Ohm's law. Eylon and Ganiel (1990) and Licht (1991) highlight this being particularly problematic to students. Additionally, this task introduced the first mathematical description of electrical phenomena in a way that allowed the students to visualise the quantitative variables and draw links between them to prior mental models.

Lesson Five and Lesson Six: Task sequence

The starter task centred around the discussion of the question 'How much current do you think it takes to kill someone?'. A multimeter was then used to measure the surface resistance of human skin using two multimeter probes pressed into the thumbs of each student, with the multimeter set as an ohmmeter. The next task gave each student one 1.5V screw thread bulb, one 1.5V cell and one wire. They were required to illuminate the bulb with only this apparatus.

The remainder of lessons five and six was used to complete the practical tasks as outlined in the AQA (2016) GCSE Physics (8463) specification for required practical 3. In order to provide a similar practical experience to all students within the year group a decision was made as a Physics department not to diverge from the suggested instructions for practical activities as outlined in the AQA (2016) GCSE Physics Required practical handbook. Thus, the practical work undertaken by the students in the intervention class was carried out in exactly the same way as the other 125 students in Year 10. However, their handouts were amended to provide further clarification and to link more explicitly with the previous activities in the topic. Each circuit diagram had an accompanying screenshot of an equivalent circuit from an Explore Learning simulation.

The practical task was also performed on a coloured piece of blue A4 paper with 20 black dots at regular intervals (see Appendix 5), this simulated the background from

the Explore Learning simulations, the components were placed such that each connection aligned with the black dots below.

Theoretical rationale: Lesson Five and Lesson Six

The first two tasks had the dual purpose of re-familiarising students with electrical apparatus and increasing engagement. In support of the first task, Baker's (2013:3) review paper identified tasks which explicitly link physics to the human body to increase girls' engagement with science. This notion was combined with the findings of Licht's (1985) study suggest danger, in relation to electricity, to be among the concepts that students find most interesting. The second task was seen suggested by a colleague as a fun task, involving an element of competition which the students would enjoy.

The main function of the two lessons was to fulfil the required practical element of the AQA (2016) GCSE Physics (8463) specification. An attempt was made to link this work explicitly with the previous simulations so the mental models which the students had created could be transferred to a new domain of physical circuits.

Lesson Seven: Task sequence

In the final lesson five rules, simplifications of Kirchhoff's laws, were given to the students in a handout. There were two rules related to current, describing how current is determined in a series circuit and in the separate branches of a parallel

circuit. There were two rules related to determining potential difference across individual components in series and parallel circuits. Finally, a rule for determining the total resistance in a series circuit. From these rules, the students were given 18 worked examples of their application using the screenshots from lessons one and two. They were then given ten minutes to discuss, in pairs, how the rules applied to each circuit. A whole class discussion followed from this.

The second task gave the students a handout with definitions of current, potential difference and resistance.

The final task gave the students the three equations:

$$1) Q = I \times t$$

$$2) V = I \times R$$

$$3) E = V \times Q$$

Where, Q, I, t, V, R and E represent, charge, current, time, potential difference, resistance and energy respectively. Worked examples were reviewed as a class and finally questions were given to complete as homework.

Theoretical rationale: Lesson Seven

This lesson provided the first formal introduction to the quantitative mathematical variables of charge, current, time, potential difference, resistance and energy. It is quite clear from the literature that mathematics is often introduced into a scheme of work before students have fully developed mental models to describe the phenomena

which the mathematical variables represent (Hestenes (1987), Larkin and Chabay (1989), Licht (1991) and Shipstone (1988)). Thus, quantitative mathematical variables were introduced after sufficient time had been assigned to the development of the students' mental models.

Ethical Considerations

This research was conducted within BERA (2011) research guidelines, a CUREC 1A form was completed and ethical approval was given to conduct this study. Consent was also given by the Headteacher of School A, who decided that 'voluntary informed consent' (BERA 2011:5) was sufficient to comply with the ethical guidelines set out by BERA (2011) as the research process did not go beyond normal practice and so parental consent from participants was not required. A copy of the letter provided to the Headteacher can be found in Appendix 6.

The focus groups were audio-recorded and the transcripts were word processed. Both the recordings and the transcripts were stored on a password-protected computer; all data was only accessible to the researcher. The quotations from the transcripts have been anonymised. The paper copies of the pre-topic surveys were stored in a locked filing cabinet. All data collected was either safely destroyed or deleted on completion of this dissertation.

The participants were informed of the nature and purpose of the research, the Year 10 focus group was comprised of four volunteers from the researcher's Year 10

intervention class and the Year 11 focus group was comprised of two volunteers from the Year 11 cohort. The students were repeatedly informed that their participation within the focus group was optional and they had the right to withdraw at any time. The focus group participants were also informed that their anonymity would be maintained and that the audio recordings and transcripts would be destroyed after completion of this dissertation. The surveys were all anonymous and participants given the option to leave the survey blank should they not want to participate.

As the researcher is also the Head of Year 10, it was understood that the majority of Year 10 are involved in numerous extracurricular and super-curricular activities. Therefore, a decision was made to limit Year 10 to one focus group of 40 minutes, this was in place of multiple focus groups taking place after each lesson. Year 11 focus group was incorporated into a voluntary, after school revision lesson and lasted ten-minutes. In addition to the demands on the Year 10 students' time, Year 11 also had significant demands on their time. As a result, it was not possible to conduct an initial focus group with Year 11 students to collaborate with them to elicit their views and experiences of the electricity unit they had studied then they were in Year 10, with a view to using their views to inform the design of the Year 10 intervention lessons. The limited focus group time reduced the 'impact of research on the normal ... workloads of participants' BERA (2011:7).

Year 10 focus group

Student voice was considered to play an important role in determining the effectiveness of the study on increasing student engagement. The assumption was made that there would not necessarily be convergence between the way in which students perceived tasks within the classroom and teacher perceptions of those same tasks. To quote Darby (2005:428) 'The students were considered experts of their own experiences and interpretations of their experiences...[therefore] student perceptions were the vehicle for developing examples of engaging teaching practice'. A similar view was taken in this study, focus groups were chosen to elicit the views the Year 10 students. An additional aim of the focus group was to collaborate with the students to look for ways in which to improve the intervention lessons.

At the end of the seven intervention lessons, four students of varying academic ability in physics volunteered to take part in the focus group. Although this is a relatively small number, Morgan (1997) and Wilkinson and Birmingham (2003) suggest that four students are sufficient to generate the type of group dynamic that is of fundamental value to a successful focus group. Wilkinson and Birmingham (2003:93) argue that focus groups are able to generate dialogue which is 'heartfelt, honest and meaningful'. Krueger (2000) believes the more informal and social setting allows students to formula their ideas. Thus, they are able to provide a level of rich detail that could not be obtained from surveys.

It is vital that the group felt comfortable with the interviewer and other group members, as their true views and the reasons behind these views needed to be elicited. It was fortunate that the interviewer was the students Head of Year, since it can be presumed that there was a strong teacher-student relationship and the participants felt comfortable conveying their true views. It was the view of the interviewer that a good relationship existed between all students and they felt able to share their ideas, without the focus group being dominated by any individual student.

The students were given copies of all of the resources that were originally used in the lessons to remind them of the tasks they had completed. A systematic discussion of the first seven lessons in the topic was carried out in the order in which they were taught. During the focus group, notes were taken of key ideas, as well as any non-verbal signs of communication such as: 'facial expressions, nods of agreement or disagreement' (Wilkinson and Birmingham (2003:20)).

The aim of the focus group was to answer the following three questions to measure the success of the intervention:

- 1) Which tasks from this intervention have been successful in increasing student engagement with this topic?
- 2) Which tasks have been unsuccessful in increasing student engagement with this topic?
- 3) How does the teaching of this topic compare to the experiences of the topic of electricity in previous years?

In addition, the following question was used to collaborate with the students, with the aim of improving the intervention lessons:

- 1) How can this topic be improved in the future to increase student engagement?

Year 10 surveys

The year group was given a pre-topic self-report survey, parts of the survey were adapted from Lindbeck (2001:50). Copies of the survey used in this study can be found in Appendix 7. The pre-topic survey was given to all six Year 10 Physics classes. In total, 144 of the 150 students in the year group completed the survey. Of this number, 23 of the 25 members of the intervention class completed the survey.

The purpose of the pre-topic survey was to collaborate with the students to elicit their ideas of engaging physics teaching, with a particular focus on the topic of electricity in order to design a series of engaging intervention lessons. As engagement is being judged in this action research study, a measure of attainment is not sufficient to measure engagement. This is particularly true in the context of a selective grammar school where the spread in GCSE results is so narrow; for example, in 2016 94% of students achieved A*/A and 98% of students achieved A*-B. Therefore, attainment data such as pre-topic and post-topic tests has not been used as an assessment of the projects' success.

Year 11 intervention

The feedback from the Year 10 focus group was used to redesign the Year 10 intervention lessons. A 70-minute, after school, electricity revision lesson was delivered to two Year 11 students. The revision lesson was originally targeted at the 12 members of the Year 11 intervention group. This group are considered to be at risk of underachieving in multiple subject areas at GCSE, including their Physics GCSE. Due to the time taken to review the focus group and subsequently amend the interventions lessons, the revision lesson was scheduled to take place at the start of the summer term. As a result of their commitment to after school revision lessons for multiple subject areas during this period, none of the intervention group were able to attend an additional physics revision lesson. Therefore, the revision lesson was offered to the remaining 108 members of the 120-student cohort; two students were able to attend from this group. The lesson incorporated the material from lessons one to four and lesson 7, the practical lessons were removed as the current Year 11 cohort are taking the old AQA (2016) GCSE Physics (8463) specification, which does not include required practical activities. Upon completion of the revision lesson, a ten-minute focus group was carried out.

Revision Lesson: Task sequence

The tasks used in the revision lesson remained unchanged from the Year 10 intervention lessons, however the sequence of tasks was altered to focus on each key piece of terminology, each task was separated and intergraded into the lesson. The

revision lesson made use of: Explore Learning simulations, 'water flowing in a pipe' analogy, two PhET simulations, definitions of key terminology, three mathematical equations with worked examples and ten pairs of 'true or false' statements pertaining to the key terminology.

The initial series of tasks provided the students with a recap of key terminology from the electricity unit. A quiz which included the same information that had been given to the Year 10 students as a homework in lesson one of the intervention was given to the students. The notable difference was the removal, at random, of half of the symbols, quantities and units. The term 'charge' was introduced using a pair of two 'true or false' statements, charge was then defined and illustrated with the 'Balloon and Static electricity' PhET demo, a final pair of 'true or false' statements was given. The terms 'current' and 'resistance' were introduced with three pairs of 'true or false' statements for each term. The 'water flowing in a pipe' analogy was introduced and the students were given ten minutes to read through and discuss them. Next current was defined, followed by the equation ' $Q = I \times t$ ' and a series of worked examples. The finally, 'potential difference' and 'resistance' were defined qualitatively and linked mathematical by introducing Ohm's law. Ohm's law was reinforced using the Phet simulation 'Ohm's law'.

The second half of the revision lesson used the Explore Learning simulations. As with the Year 10 lessons, screenshots of circuits were provided on a handout and the students were required to build 10 circuits.

The current, potential difference and resistance were recorded at various places around series circuits which included: wires, cells, bulbs and resistors. Parallel circuits were then introduced, the students were required to measure the potential difference across the resistors and/or bulbs in the network and the current was measured and recorded at various places around the circuit.

The plenary remained the same as in lessons two and three of the Year 10 intervention, the students commented on the potential difference across and the current through individual branches of three screenshots of parallel circuits. In addition, they were required to make five statements which gave general rules for the flow of current in series and parallel circuits, the calculation of combinations of resistors in series and the potential difference across various components in series and parallel circuits.

Theoretical rationale: Revision Lesson

The rationale for this lesson stems from the analysis of the Year 10 focus group and as such will be detailed in full in the discussion section of this paper. The underlying principle is that the group felt that there was a general lack of synthesis within the intervention lessons; the activities in each lesson were taught in isolation, with the general aim of introducing the students to that task, rather than each underlying principle. The group believed that each task would have been more beneficial if multiple elements of each task had been taught in each lesson. For example, an

approach to teaching current that incorporated simulations, analogies and key definitions in the same lesson.

Year 11 focus group

At the end of the revision session, the students were asked to share their views on the revision lesson, in a ten- minute focus group. The aim was to use the focus group to determine the effectiveness of the revised lesson sequence on increasing engagement with a group of students who had already studied the topic.

The first three questions posed to the Year 10 focus group were used:

- 1) Which tasks from this intervention have been successful in increasing student engagement with this topic?
- 2) Which tasks have been unsuccessful in increasing student engagement with this topic?
- 3) How does the teaching of this topic compare to the experiences of the topic of electricity in previous years?

Discussion

Survey results

The results of the pre-topic survey are largely inconclusive. An attempt was made to code and group the students' responses to the questions to elicit the students' views of engaging and disengaging physics topics and tasks. However, there was a large amount of divergence between each students' views, therefore common themes were not able to be elicited. The use of surveys to collaborate with students in the development of a sequence of lessons has not been successful as neither the responses from Year 10 as a whole nor the intervention class were sufficient to provide suggestions for developing the intervention lessons. It would have been preferable to have given the survey or held a focus group with the current Year 11 students who had already completed the electricity unit. However, as previously stated this was not able to occur due to the pre-existing constraints on the students' time.

Year 10 focus group analysis

A systematic analysis of the audio recordings from the focus groups held in March and April 2017 was carried out using grounded theory (Bryman and Burgess (1994:4)). The responses to each of the questions detailed below were recorded in an analysis table, and repeated ideas and concepts were grouped together:

- 1) Which tasks from this intervention have been successful in increasing student engagement with this topic?
- 2) Which tasks have been unsuccessful in increasing student engagement with this topic?
- 3) How does the teaching of this topic compare to the experiences of the topic of electricity in previous years?
- 4) How can this topic be improved in the future to increase student engagement?

Question 1: Which tasks from this intervention have been successful in increasing student engagement with this topic?

In response to question one, the focus groups' views suggested positive engagement with: the illuminating bulb task, the national grid task, the Ohm's law PhET simulation and with the 'crowded room', 'water flowing in a pipe' and 'bath' analogies. The key elements which resulted in positive engagement were:

- 1) Collaboration with peers, experienced in both of the analogies and national grid tasks.
- 2) Personal relevance, experienced in three of the analogies.
- 3) Competition with peers, experienced in the national grid and bulb illumination tasks.
- 4) Synthesis of prior information, experienced in the national grid and Ohm's law tasks.

The analogies task dominated a large proportion of the focus group time, as a result this task will be disproportionately represented below.

Collaboration with peers

Of all the tasks delivered in the series of intervention lessons, the analogies task was reported to have been viewed in the most positive way. In general, the students found that working in groups made the development of their individual mental models more clear. This was reported to have been for two main reasons. Firstly, during the initial stage of the task, where each student became the 'expert' of their analogy, the students felt that they were able to talk to their peers to clarify any misunderstandings:

Student A: 'Looking at it in groups before meant you got proper knowledge of your card before, so there has got to be someone in your group who understands.'

Student B: '...there were at least three other people in the room that had the same card as you so if you are stuck you can speak to someone.'

Student C: '...if I was confused by something on my own card, having someone else look at it as well and work with you was really helpful because everyone thinks differently. Like what they were saying, if you get stuck on one thing the chances are your partner will get that bit. I like doing group work.'

The group suggested that hearing their peers describe a concept to them, as opposed to reading it, was incredibly beneficial.

Student A: 'Just the way people describe something when you get to hear it, I think makes stuff make sense.'

Student B: 'I learn a lot better from hearing people say stuff than reading it myself.'

The second element to collaborative work that was reported as being positive, was when the students had to explain their analogy to those who were unfamiliar with it. The group suggested that both explaining a concept and knowing that they would soon have to explain a concept to others in the group, meant that they engaged with the task more:

Student B: 'You had to make sure you knew what you were talking about as well, which meant that I actually remembered it.'

Student C: 'You can't just read off the card because then everyone would be just as confused as you are.'

Student D builds from these ideas by introducing the idea that knowledge isn't just passed from one student to another, learning can be built as a community. She also suggests this can occur using non-verbal methods of communication:

Student D: 'The fact that you had to pick out the information made the analogy make more sense, if I had just read through the cards, I wouldn't have really put it into context. But when you have to explain it and a lot of people are going "this is here, this is here", using the hand movements as well, it makes things make sense.'

Student D suggests that although explaining the concept to others caused her to focus on specific information and as a result develop a better understanding herself, the students in the group who were not 'experts' of a particular analogy were also able to help her to understand her analogy in a deeper way.

The students were not able to give a detailed description of the national grid task, they simply made reference to the analogies task to justify why they felt it was engaging:

Student D: ‘... just like when we did the analogies, you could talk to everyone and that helped me understand what was going on.’

Student C: ‘Yeah it was the same, I like working with everyone.’

They held the view that although the task did not allow for the same level of collaboration as the analogies task, they valued the opportunity to hear the opinions of others during the task and felt that this helped to clarify any misconceptions.

Personal relevance

The group reported very positive responses to the ‘crowded room’, ‘water flowing in a pipe’ and ‘bath’ analogies. They were in agreement that the personal relevance of these analogies enabled them to easily incorporate the concepts into their pre-existing schemas (Rumelhart (1983)). Stadler, Duit and Benke (2000) note that students frequently interpret physical phenomena in terms of human behaviour. When talking of the ‘crowded room’ analogy, Student A presents the general view of the group that this type of interpretation is incredibly useful for making meaning from an analogy:

Student A: ‘It was like we are the energy trying to get through the hallway and the Year 7’s are blocking us and that’s the resistance. And it’s really easy to remember because it happens every day.’

The two water based analogies of ‘water flowing in a pipe’ and the ‘bath’ were also considered positively:

Student C: ‘... it’s simple and applicable, whereas most of the others are quite complex and it’s not the sort of circumstance you see yourself in. You can understand being in the bath because most people have had a bath.’

Student B added that the analogies were relevant to her because they did not conflict with any of her existing mental models of electricity:

Student B: 'I kind of liked all the ones with the flowing, so like the one in the bath and the pipe made more sense. I think it's the ones that you know sound more like electricity is, like the flow so something like water just made it make a bit more sense.'
Student D: 'We are all in that position every day, [it's] a lot more simple than trying to imagine something you have never had to imagine before.'

The group highlighted that in order for an analogy to be effective it needs to be with a familiar situation; there is no value in introducing an analogy with an unfamiliar situation. This requires a student to comprehend the subtlety of the unfamiliar situation, before then applying this new understanding to an analogy. Thus, adding an additional stage in the construction of a working mental model. In this case, time would be more wisely spent teaching the situation without the aid of an analogy.

The results of the lesson questionnaire, completed by 22 of 25 students in the intervention class, are in strong agreement with the aforementioned comments from the focus group. When asked to vote on their preferred analogy, eight students favored the 'crowded room' analogy, seven students favored the 'water flowing in a pipe' analogy, four students favored the 'bath' analogy and three favored the 'rope loop' analogy. It is clear that the class favoured the 'crowded room' and 'water flowing in a pipe' analogies. The questionnaire can be considered to be unbiased as there were approximately equal numbers of student 'experts' assigned to each analogy. However, the opinions of dominant group members or the quality of explanation delivered by each individual group member cannot be ruled out as possible causes of bias.

Competition

In the task that required each student to illuminate a bulb, there was a spontaneous competition within the class to light the bulb faster than their peers. As this task was very different to the tasks that are typically used in physics lessons, the students recognised this as having no direct application to an examination setting. Thus the 'high stakes' element of the task was removed and the students were able to engage with it in the way that had been intended, as a fun starter activity:

Student A: 'It was a bit of fun.'

Student B: 'I mean, competitiveness is good.'

Student C: 'We loved it, I mean especially because of the time of week that we have our lessons.'

Student D: 'You need to keep us engaged or we are going to fall asleep. It's like fifth period on a Friday, unless we are enjoying ourselves we all just want to go home, so where there are like little things that just sort of make you forget that you could be going home in 15 minutes, then it makes the lesson a bit better.'

Student C: 'You're not meant to say that.'

The focus group also reported that each group enjoyed trying to be the first to recall all of the key information they had learnt in Year 9 during the national grid task: it was being in competition with other groups that provided the engagement in the task. A deep level of dialogue was not offered, Student A stated: 'The element of competition was good'. However, it was clear during the lesson that although the groups were rushing to be the first to finish, the class were all engaged in the task and all eight groups had produced an A3 sheet with a thorough description of the process. It is of note that competition was not introduced as a facet of the task, the students decided to compete of their own volition.

The unintentional inclusion of two competitive tasks was viewed as having a positive impact on student engagement. It would seem that the level of engagement reported by the focus group in relation to these tasks do not agree with Smithers and Hill's (1987) view that girls are uncompetitive. They agree with the findings of Mujtaba and Reiss (2016), that high ability students are competitive. In the case of these students, they enjoy an element of competition.

Synthesis

The group strongly felt that tasks that allow for the synthesis of ideas by enabling them to draw links with previous years' work, previous lessons' work or work from earlier in a lesson is very important. The national grid task allowed them to draw on their prior knowledge before starting a new lesson; this was seen as valuable as it placed the work into a wider context.

There was also a similar sentiment regarding the Ohm's law task. Although the group recognised the benefit of the simulation itself, the engagement stemmed from being able to use it to develop a wider appreciation of the other work they had studied:

Student D: 'I didn't understand Ohm's law before, or a lot of the other work, but when we were given it like this, everything made sense. Then I used it to help with other parts of electricity.'

The group raised the issue of synthesis in more detail when they gave their suggestions for improvements to the intervention lessons, this will be explored more fully in the discussion of question four.

General comments

In addition to the views which have been expressed which are common to multiple tasks, the students' statements surrounding the use of multiple analogies are in agreement with the aforementioned literature. The group felt that they engaged more by being presented with multiple analogies:

Student B: 'There were some good and some bad [analogies], you have got to find a good one.'

Student C: 'The ones I did understand helped me remember it.'

Student D: 'Everyone is going to find a different one better because everyone thinks differently so if we were only given one it would leave a lot of people very confused. Whereas when we are given lots... it made you learn it better because you had to think about it.'

The group are acknowledging that each student will find different analogies helpful, thus being presented with multiple analogies is valuable. This is subtly different from the suggestion by Williams (2011), that being presented with multiple analogies enables students to use all of them to then develop a mental model, whereas the focus group seem to suggest that when presented with multiple models, they can choose one and find meaning from that. However, this does not undermine the use of multiple models, it simply suggests a different rationale for their use.

Question 2: Which tasks have been unsuccessful in increasing student engagement with this topic?

Although the focus group presented strong views with respect to the question above, their views were not as numerous as in the previous question. The group discussed two main causes of disengagement, the practical lessons, in their entirety and tasks to which they could not relate.

Of all the tasks in the intervention lessons, the only tasks to be regarded as actively disengaging, were the practical tasks, this was true of all tasks in both practical lessons. Despite the explicit link to the Explore Learning simulations through the use of diagrams, the group felt that the tasks were too abstract and could not see a purpose to the tasks they were being asked to perform. When discussing the tasks, the group stated:

Student B: 'I can't remember doing practicals, I remember being there and doing something but I can't remember what we did. There was just a lot of plugging in different wires.'

Student C: 'All of the practicals were kind of plugging in things differently, it wasn't really interesting as such.'

Student A: 'Yeah, no. But I don't think circuits can be interesting.'

Student A: 'Yeah generally we don't really find circuits interesting.'

Student C: 'Yeah, I mean when you were six it was quite fun to light up a bulb.'

Student B: 'It's not that our lessons aren't interesting. We all have a laugh in the lesson, but it's just the content is just dull.'

It was clear from their dialogue that the students did not engage with the tasks cognitively or emotionally as they perceived them to be 'a rote sequence of steps'

(Davis et al (2008:4). This is despite the suggestion of Davis et al that tasks which allow student to evaluate their mental models against empirical evidence, promote meaningful engagement. It would seem that the students were either unable to develop mental models during the previous tasks or despite having empirical evidence to support their models, students need to be able to see the personal relevance of a task in order to find it engaging, as suggested by Murphy and Whitelegg (2006) and Stadler, Duit and Benke (2000).

It is of note that although the group found this task disengaging, the group did value the opportunity to work with and learn from other students, further corroborating their responses to question one:

Student C: 'When we got stuck, usually someone from the other group would be like oh you have just put this in the wrong place and it was really easy to fix if we missed what we had done wrong.'

The necessity for personal relevance was also noted by the focus group when discussing the 'gravitational potential' and 'rope loop' analogies. They found them confusing as they related to physical situations which they have not experienced:

Student B: '...it is difficult to imagine something you have never had to imagine before.'

Student C: 'It's just like imagining another circuit, you may as well learn the first circuit.'

As the students had no prior concept of the physical situations, they found it difficult to make meaning from the tasks. The results of the class questionnaire are also in

strong agreement with the aforementioned comments. Fifteen of the students in the intervention class gave the 'gravitational potential' analogy as their least favorite analogy and the remaining seven chose the 'rope loop' analogy. However, these findings are in direct contrast to the recommendations of the IOP⁴ (2017), which state that: 'We think that the rope loop provides a powerful mechanical analogue of the electrical loop. It's tangible, manipulable, and the physical quantities map well onto the electrical quantities.' It should be noted that in the intervention lesson, a physical loop of rope was not provided as a description was considered sufficient to illustrate the analogy loop.

Although the group have given strong evidence to suggest that the personal relevance of a task is of particular importance, their views were not entirely consistent throughout. During the 'Balloon and Static Electricity' PhET simulation, Student B gave a conflicting view to one already shared. She suggested that it is more difficult to develop an understanding of a concept which one sees every day. This is in contrast to learning about an abstract concept such as fission, for which the only conceptions have been built during a physics lesson:

Student B: '...you just sort of have your own idea of, well electricity just flows through the plug, but you never sort of as a kid went, oh look at the charge in the bulb and all of that. So, it's sort of like unlearning your typical "electricity just flows" and you've got to learn the specifics. Which I think is harder because for more abstract things you don't have that presumption in the first place.'

⁴ (<http://supportingphysicsteaching.net/EI01TL.html#12> [Accessed 17 September July 2017])

The other members of the group disagreed with this idea, reaffirming their previously held views. As a result of the inclusion of some potentially contrived tasks such as measuring the resistance of skin, there is the possibility that the students gained an appreciation of the researchers' motivation to incorporate tasks with perceived personal relevance and as a result their views were biased towards pleasing the interviewer.

Further to this, although the focus group did not report the task which required the measurement of the resistance of human skin to be disengaging, they reported a general level of indifference towards the task. This is despite the suggestion of Baker (2003), that tasks which link to the human body increase girls' engagement. Thus, it could be argued that while in general, linking tasks to the human body may increase engagement, this is negated if the task is considered by the students to be too contrived.

Question 3: How does the teaching of this topic compare to the experiences of the topic of electricity in previous years?

In School A, the current Year 10's prior teaching of electricity was exclusively carried out in 2013, when the students were in Year 7. Due to staffing issues within School A in this year, four of the six Year 10 classes were taught by multiple, non-specialist substitute physics teachers. As a result, the prior teaching of electricity has been reported to have been very limited and the experiences the group report are relatively negative:

Student D: 'I don't remember ever learning electricity.'

Student A: 'I don't think we have learnt electricity before.'

However, there was disagreement with Student C and Student D, who were taught by the interviewer in Year 7:

Student B: 'Have we done electricity before in school.'

Student C: 'We had you teach us in Year 7, we were fine.'

Student A: 'I feel like no one likes electricity anyway, so even if they had done it before then no one would have remembered it.'

Student A's comment is quite apt, as although half of group were certainly taught electricity by the interviewer, the groups' dispute represents a deeper problem. The group could not offer any of their experiences of the electricity topic in Year 7, irrespective of whether they remember being taught the topic. All students in Year 7 received, although to differing levels, teaching of electricity. However, as they cannot remember it, this would suggest the students certainly did not engage on a cognitive level and possibly not an emotional or behavioral level.

Question 4: How can this topic be improved in the future to increase student engagement?

Throughout the focus group, there was the strong suggestion that the group would have engaged more with the lessons if a greater emphasis had been placed on the synthesis of ideas. They suggested that although they engaged with most tasks individually, each task should have been separated and combinations of elements from each task should have been used in each lesson to teach 'current', 'potential

difference' and 'resistance'. This would have allowed them to see explicitly where each new concept had linked with concepts they had learnt in previous intervention lessons and in some cases previous years. This was expressed particularly clearly when discussing the Explore Learning simulations:

Student B: 'It would have been more helpful if synthesised with the relevant idea, either as a recap or taught before the lesson.'

Student C: 'This would have enabled you to understand what the numbers meant in the simulations task.'

It would seem from their responses that due to the abstract nature of the topic, they were unable to draw links for themselves between the content of each lesson.

The group also discussed the lack of general synthesis with the content from previous lessons as a cause for disengagement during the practical lessons. The group would have preferred to have a recap before each task of 'current', 'potential difference' and 'resistance'.

There was a division between the two students who were more mathematically able and two students who were less mathematically able. The more able students would have liked to see a quantitative treatment of variables earlier in the course, they believe it would have aided their understanding by allowing them to see the purpose of the Explore Learning simulations:

Student C: 'I feel like it would have been easier with the equations, I would have known if the numbers were right.'

However, the other students did not concur:

Student B: 'It's because we did them later on that they made everything make sense ... if we have been given an equation I would have been like ok so I know I need to work something out but which one do I have to use? But because we did everything later on it sort of made everything clearer rather than being confused with an equation.'

Although the group were able to give their views on the ordering of tasks, they were not able to offer any other deep insights into how to improve the tasks. The group made several suggestions pertaining to general task design, however their views were conflicting. Student D felt that she benefitted from writing notes and drawing diagrams, however this was fiercely disputed by Student A, who felt that lots of time is wasted during lessons on writing notes. As all notes were given to the students during this intervention, the view can be taken that this is a difficulty that Student A finds with the interviewer's general task design in previous lessons. Student C felt that lots of time is wasted during lessons on sticking in notes that have been printed, she offered the view that printed notes should be provided with gaps that could be filled in, or key words could be highlighted. It would seem that there is a general divergence in the majority of the students' views.

Year 11 focus group analysis

This section outlines the Year 11 focus groups' responses to the three questions outlined below. As the duration of the focus group was only 10 minutes, the responses are less detailed than those of the Year 10 students. In addition, as there were only

two students who volunteered to participate in this focus group, the dialogue did not provide a particularly rich level of detail. Wilkinson and Birmingham (2003) do not recommend carrying out focus groups with fewer than four members.

Question 1: Which tasks from this intervention have been successful in increasing student engagement with this topic?

The students found the Explore Learning simulations to be the most engaging tasks, they felt they were being given time to develop their understanding of circuit phenomena:

Student F: 'I feel like the direction that the current is flowing in is definitely helpful'.

Interviewer: 'Do you prefer it to actual physical circuits?'

Student E: 'Yeah, yeah, yeah, yeah, so much! Oh, so much, literally half the bulbs don't work, then you put it together and it takes the whole lesson and you don't get much out of it, no offence.'

Student F: 'You can see the immediate result of the voltmeter and stuff.'

Without the barriers to understanding which are inherent in the use of physical circuits, the students were able to engage with the task in a more meaningful way. The visual representation of current in the simulation allowed the students the opportunity to develop a deeper mental model of the flow of current and potential difference. The simulation allowed reading to be taken that were not dependent upon their practical capabilities.

Question 2: Which tasks have been unsuccessful in increasing student engagement with this topic?

The students were very positive in their responses to this intervention, they did not state an element of the lesson which they found disengaging. Although they appeared to be comfortable with sharing some of their views with the interviewer, as there were only two participants, it is possible that they perceived a power dynamic to have existed during the interview. As a result, they may not have felt comfortable expressing views which they believed would be seen as negative.

A level of disengagement was observed by the interviewer when the students were required to make five statements which gave general rules for the flow of current in series and parallel circuits. They had particular difficulty with understanding and using the key terminology in the topic, this seemed to cause a level of frustration and subsequent disengagement as they could not express their ideas as clearly as they wanted. The terms 'current through' and 'potential difference across', seemed to present the students with the greatest problems. This is in agreement with Stocklmayer and Treagust (1996) and Farrell and Ventura (1998), who have found these abstract concept words (Wellington (1982)) to be regularly misunderstood by students.

Question 3: How does the teaching of this topic compare to the experiences of the topic of electricity in previous years?

In general, the students were rather negative towards their prior experiences of electricity teaching, they did not feel they were given the time to develop a deep understanding of the material:

Student E: 'Usually it's just the definitions, that's about it.'

Student F: 'Just memory work, it's just surface, it doesn't go into the depth, like the reasons.'

Student E: 'I think teachers assume that we know what current is, but we don't, we just use it. [Teachers should] start from the bottom without just chucking definitions at us.'

Licht (1991) argues that students would benefit from being assigned more time to develop a deeper understanding of the concepts within their working mental models.

It is clear from the responses to question one that the students had not been given tasks to help develop their mental models, for example they had not seen any electrical circuit simulations before.

The students also raised an issue which Hestenes (1987) has found to be a wider problem in the teaching of electricity. There is an early focus on the use of mathematical equations to find the solution to a problem which they are not adequately equipped to understand. They stated that the sequence of tasks in this lesson was beneficial to them:

Student E: 'when we were learning about parallel and series circuits, we were just given equations for resistors in a series circuit, but it's easier to visualise it when its physically in front of you.'

Student F: 'Before, I feel we could get by in an exam with the equations that we know, but we didn't really understand it. But now we understand.'

Student E: 'When you just memorise the equation " $T_{\text{otal}} = V_1 + V_2$ ", it's harder.'

Student F: 'Bringing in the equations then makes the situation complicated.'

It would seem that their prior teaching of electricity did not allow them to draw links between the circuit phenomena they were learning and the quantitative mathematical description of those same circuit phenomena, Shipstone (1988) notes that this is a common problem in electricity teaching.

Summary of findings

The findings of this study give strong evidence to suggest that the intervention was successful in increasing girls' engagement when using tasks which allowed the synthesis of information they had previously learnt and which linked explicitly to contexts with which they were familiar. This is in general agreement with much of the literature on girls' engagement with physics.

It was found from the Year 10 students that tasks which allowed collaboration with, and competition between, peers were both successful in increasing engagement.

Collaboration is commonly seen in the literature as increasing engagement. However, the use of competition among girls is now widely seen as being conducive to increasing the engagement of girls.

With respect to electricity, tasks which allowed the students to develop a deep understanding of circuit phenomena were successful in increasing engagement. For this reason, students are not able to engage with the topic if the mathematical treatment of electricity is introduced before they feel they have truly understood the circuit phenomena.

Conversely, the tasks which did not contain any elements of collaboration or synthesis or tasks which were not seen as personally relevant were not successful in increasing engagement.

Recommendations

In order to improve girls' engagement with electricity, the recommendations of this paper are comprised of two parts, those which pertain solely to the teaching of electricity and those which are applicable both to electricity and to physics in general.

When teaching electricity, it is recommended that a sufficient amount of time is dedicated to the development of a deep understanding of the circuit phenomena, 'current', 'potential difference', and 'resistance' at the beginning of the course.

Analogies and simulations should be used to facilitate the construction of students' mental models. This will help them to develop a deeper understanding of the circuit phenomena. In addition, the mathematical treatment of variables should be left until later in the course, when students have developed detailed mental models which allow them to understand the aforementioned phenomena.

There are three suggested recommendations for general task design. Firstly, teachers and educators should always look for ways in which the current task can be linked to prior knowledge, either within the current topic or within the physics course in general. This can involve the student making the link for themselves or if this would not be possible, the teacher can make the link explicit for the students. Secondly, where possible, tasks should be designed which allow students to collaborate with each other. Finally, tasks should be designed in such a way as to allow students to assign meaning, through making them personally relevant.

Further work

To further develop this study, pre-topic and post-topic engagement surveys of Year 10 would have provided a larger sample of evidence from which to judge the success of this intervention.

Repeat interviews would have allowed the Year 10 focus groups' ideas surrounding competition to be expanded upon. This idea does not feature frequently in the literature as a cause of engagement. Had extension of the duration of the interview not resulted in 'bureaucratic burden' (BERA (2011:7)), this idea would have been explored until 'saturation' (Bryman and Burgess (1994:4)), in order to elicit a deeper understanding of its importance.

In addition, the Year 10 students were unable to offer many detailed suggestions for the improvement of the intervention. It would have been useful to have either carried out a Year 11 focus group or to have given the Year group a survey to elicit their ideas

of engaging teaching of electricity. However, as previously stated, this was not possible due to time constraints.

Further collaboration

The findings of this study and the resources generated for the intervention lessons were shared with the science department of School A during an additional 30-minute departmental meeting during the summer term.

The science department is comprised of four physics teachers, five chemistry teachers and six biology teachers. All teachers from School A are required to teach physics to KS3 and the four physics teachers teach physics at GCSE level. As a result of the findings, work has begun to incorporate the Explore Learning simulations, PhET simulations and the 'crowded room' and 'water flowing in a pipe' analogies into the KS3 curriculum. It was decided that this would result in the greatest impact on the physics teaching at School A, as there are a number of non-specialist teachers who teach physics at KS3. In addition, the results of the Part 2 study found a surprising number of students who reported that when making the transition from primary school to School A, their expectations of fun and engaging secondary school science lessons, were not met. A focus on increasing the engagement of younger students will mean they will not have already become disengaged with physics by the time they reach KS4.

Conclusion

Due to the level of abstraction, it is incredibly difficult for girls to find personal relevance in many elements of the topic. Although personal relevance is only one of the elements which the students have suggested results in engagement, it is very important.

Despite engaging with many of the tasks during the intervention lessons, the students were not engaged throughout the intervention. Student B seemed to speak for the group when stating: 'It's not that our lessons aren't interesting. We all have a laugh in the lesson, but it's just the content is just dull.'

It may initially seem that the topic of electricity naturally lends itself to linking explicitly with the everyday experiences of students, as the use of electricity forms an integral part of the daily lives of all students. In reality, however, it is very difficult to design tasks that are both explicitly linked to the curriculum and relevant to students' everyday experiences, whilst at the same time not seeming contrived.

However, there were elements of many of the tasks in this intervention that were shown to increase engagement, both relating to general task design and specifically to electricity. Synthesis and collaboration during tasks featured as two important elements that students reported as increasing engagement. It is relatively straightforward to include both elements in most tasks.

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Appendices

Appendix 1

Analogies

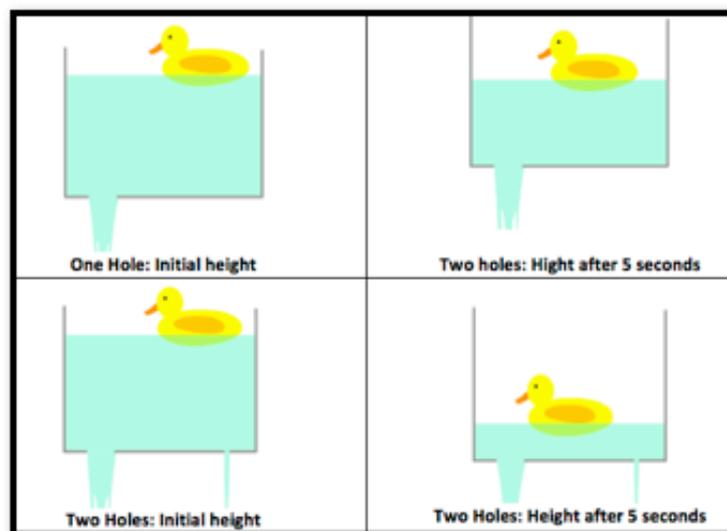
Bath analogy
{Resistors and current in Parallel}
[Problem: Everything Else]

The cell of a parallel circuit doesn't 'know' what's connected to it. All it feels is an overall **resistance** of the circuit. The **resistance** that the cell feels is called the effective resistance of the circuit.

If you have a bath with a hole in the bottom it will empty. If you add another hole, no matter how small, the bath will always empty quicker.

As you add more and more components in parallel the **current** drawn from the supply gets bigger and bigger. If the **current** gets bigger then the **resistance** must be getting smaller. So, by adding resistances you actually decrease the effective resistance, which seems odd.

It doesn't matter how enormous the resistance is, adding it in parallel always make the effective resistance go down.



Crowded room
{Series Circuit: Resistance, Potential difference and Temperature}
{Problem: Anthropomorphic}

Imagine you are running through a crowded corridor, it takes a lot longer if the crowd is moving about rather than standing still.

Here you represent an electron and the other people represent the positive ions in the lattice of a metal and the corridors represent the conducting wires. If the corridor becomes narrower further down, you are more likely to bump into people. This narrow corridor represents a resistor.

You are running from one end of the other due to academic pressure to get to the lesson on time, this represents the **Potential Difference** given by the cell.

If the people start to become agitated and move more, it becomes more difficult for you to pass through. This represents an increase in temperature.



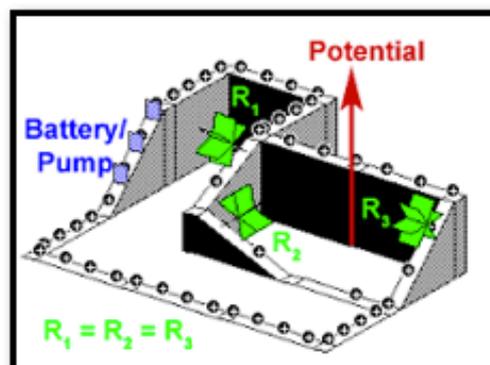
Gravitational potential analogy
(Series Circuit: Potential Difference, resistance, charge)
[Problem: Current]

This analogy equates height and therefore gravitational potential energy with **Potential Difference** in a circuit.

It can be shown by having a lift that raises a collection of balls to a given height, representing the **Potential Difference** of the cell. The higher it's raised the bigger the cell's **Potential Difference**. The balls roll under gravity, often down stairs of varying heights (representing the **resistance** of difference resistors).

You can see that the total gravitational potential energy (GPE) lost by a ball rolling down the stairs is the same as the GPE it gained being raised by the lift.

The number of balls does not change; representing the total number of charges is always the same.



Water flowing in a pipe analogy
{Series circuit: Potential Difference, Current and resistance}
{Problem: Charge}

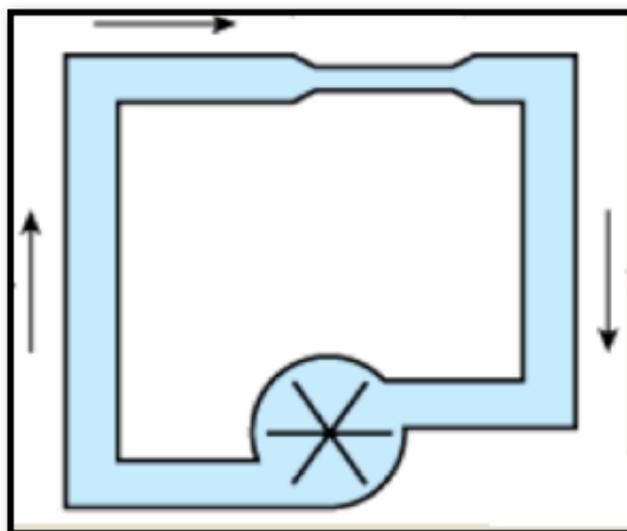
In this analogy, a cell is seen as a pump that is already full of water. The flow of water in pipes represents the flow of **current** in a circuit.

The water flows because of the pressure difference caused by the pump; a more powerful pump means that there is more pressure in the pipe system. This shows that a higher **potential difference** cell causes a large **current** as it is the potential difference that causes current to flow. The idea of **potential difference** is often explained as a difference in pressure across either side of the constriction.

Resistance is shown as constrictions in a pipe, a narrow constriction means a large **resistance** so you also have the relationship large **resistance** means small **current**.

Disadvantage:

This analogy has problem in that there's no obvious way to represent the moving **charge** and the **energy** that they carry. There is no distinction between what goes around and round (water) and what gets transferred (pressure?).



The Rope loop analogy
{Current, Charge and Resistance in Series}
[Problem: Potential Difference]

In this analogy, a circuit is modeled as a big loop of rope. One person is the cell and pulls the loop through their hands. Another person is the **resistance** and squeezes the rope. Friction with the hands of the resistor person means they can feel the energy transferred as heat.

There are some nice points to this analogy. For example, it's clear that energy is transferred very quickly, even though the rope can be moving quite slowly. This emphasizes the idea that the **charges** are already there and they all start moving everywhere at the same time.

You can also intuitively get big **resistance** means small **current** and you can see that energy is transferred where there is a big resistance.

A disadvantage:

- 1) It's not very good at explaining **potential difference** or **power**.
- 2) Unless the cell person is very disciplined at keeping the tension in the rope constant, rather than trying to make the speed of the rope constant, you might get the impression that the bigger the **resistance** the quicker energy is transferred.

In other words, there's quite a temptation for the cell person to pull harder and harder as the resistance increases. So, they'd think that big resistances make the cell work harder. This is an example of the constant current misconception.

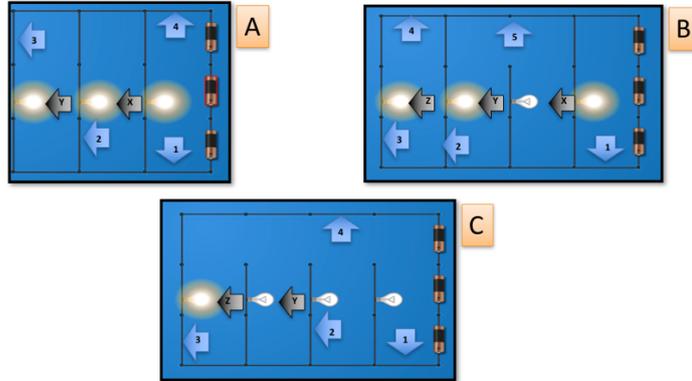
In fact, the opposite is the case. If you make the **resistance** really big, the **current** is really small and the energy transfer is very slow.



Appendix 2

Bulbs in Parallel

Measure the Potential Difference and Current at each of the positions indicated with the arrows. Set the Voltage of each cell to 4V



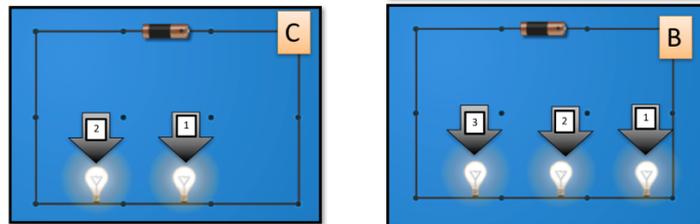
Potential Difference across Bulbs in Series

Set the voltage of the cell to 3V.

Use the Voltmeter:



To measure the Voltage across each bulb.



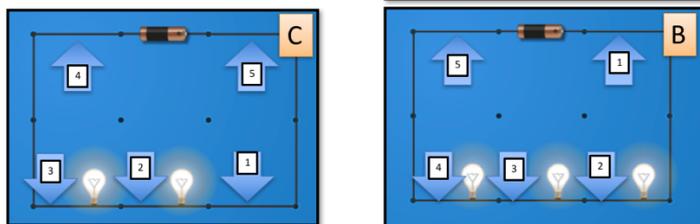
Current through Bulbs in Series

Set the voltage of the cell to 10V.

Use the Ammeter:

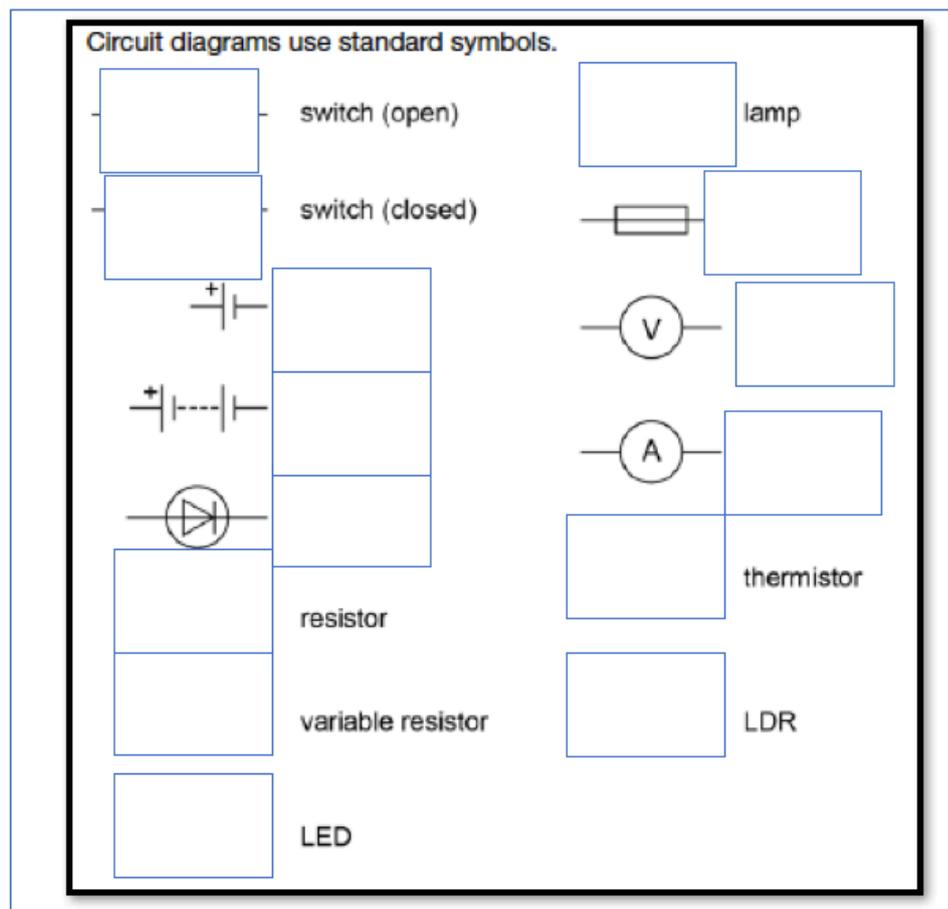


To measure the current at each position shown.



Appendix 3

Quantity	Unit	Measured in	Symbol in equations
Charge			
			V
Resistance			R
	Joules	J	
Current			I
Time	Seconds		



Appendix 4

For each of the following pairs of statements, one is correct and one is false. You need to decide which is which.

1. A) Batteries supply charge to a circuit.
B) Batteries supply energy to a circuit.
 2. A) Light bulbs use up charge.
B) Light bulbs use up energy.
 3. A) A complete circuit is always required for an electric current to flow.
B) As long as one connecting wire joins to a battery, a complete circuit is not needed to make a current flow.
 4. A) An electric current is a flow of charge.
B) An electric current is a flow of energy.
 5. A) An electric current is due to the movement of electrons.
B) An electric current is due to the movement of protons.
-
6. A) The electric current in a circuit will always be less after passing through a light bulb.
B) The electric current in a circuit will always be the same after passing through a light bulb.
 7. A) Conductors have very low electrical resistance.
B) Conductors have very high electrical resistance.
 8. A) Electrical connecting wires are made from copper as this has little resistance.
B) Electrical connecting wires are made from copper as this has high resistance.
 9. A) A battery is a collection of electrical cells joined together.
B) An electrical cell is a collection of batteries joined together.
 10. A) The greater the resistance in a circuit the greater the current.
B) The greater the resistance in a circuit the lesser the current.

Appendix 5
Black dots



Appendix 6

Headteacher Letter

UNIVERSITY OF OXFORD
DEPARTMENT OF EDUCATION

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general.enquiries@education.ox.ac.uk www.education.ox.ac.uk

Director Professor Jo-Anne Baird



Mr A
A Girls' School
England
(05/01/17)

Dear Mr A,

I am writing to enquire about conducting research in school this academic year. As you know, I am studying for the Master's in Learning and Teaching at Oxford University, supervised by Dr Ann Childs. In my final research project "How can the topic of Electricity be taught in a way that engages Year 10 students with GCSE Physics?". I will seek to determine the types of activity that KS4 students find engaging with relation to the topic of electricity.

The research will take place with one Year 10 physics class working towards GCSE. I am developing ways of increasing student engagement using a variety of tasks, both in my lessons and with colleagues. My research focus is on students' engagement, and how teachers can be increased.

By participating in the research, the school would be contributing to a project that will [*deepen our understanding of girls' engagement within the electricity topic at GCSE and so contribute towards developing ways of improving attainment for students in the school in the future. It will also contribute to Physics education more widely.*]

[I hope to conduct this research between January 2017 and April 2017. I would audio-record students engaged in two separate focus group study and carry out two surveys of the Year 10.

Oxford University has strict ethical procedures on conducting ethical research, consistent with current British Educational Research Association guidelines. As practitioner research however, the University recognises that schools have the highest ethical standards in any event. Therefore, only your formal consent as headteacher is necessary, and not that of individual parents or staff. However, throughout the research, students and other teachers will be able to refuse to participate in any research activities at any time.

All participants, including students, teacher and the school, would be made anonymous in all research reports. The data collected would be kept strictly confidential, available only to my supervisor (NAME email) and me, and only used for academic purposes. It will be kept for as long as it has academic value.

If you feel you would like to take part in the study, or need more information about what is involved, please contact me or my supervisor. Further, if you have any questions about this ethics process at any time, please contact the chair of the department's research ethics committee, though: research.office@education.ox.ac.uk

I look forward to hearing from you.

Yours sincerely,

How can the topic of Electricity be taught in a way that engages Year 10 students with GCSE Physics?

Jake Telford
University of Oxford, Department of Education]

School A

England

Mr A

- We do not wish to participate in this project.
- We would like to find out more about this project.
- We would like to take part in this project.

Mr A

Head teacher's signature

Please return this form to me.

Thank you for your help.

Appendix 7
Survey

Year 10 Electricity Survey

This survey is anonymous; please do not write your name on the top.
We would be grateful if you answered every question as honestly as possible.
You will be given approximately 10 minutes to fill it in, so please read through carefully.

1) Is there anything specific that you would like to learn during the electricity -
topic?

2) What interests you about the topic of electricity?

3) What interests you least about the topic of electricity?

4) What do you like most about physics lessons?

5) What do you find least interesting about physics lessons?