Why science is difficult to learn

Johnstone (1991) confirms that science was once easy to learn and teach. This was a time before modern scientific advancements when everything was clearly defined and separated into distinct sections and no learner was asked to apply their knowledge to an abstract situation. But Johnstone asks: ‘ Was this science?’

There seems to be an inherent idea held within society that science is difficult to learn. This essay will highlight some of the barriers to learning science and address why the idea is held that science is difficult to learn; it will then progress to identify some strategies which could be used in order to lower these barriers and make science more accessible.

Part One – Why can science be difficult to learn?

Through classroom observations and wider reading it is apparent that there are many different barriers to learning science. These barriers can be due to many different factors; cognitive development, practical, financial and psycho-social; especially motivation and relevance of the subject material.

Appendix 1 shows the ’10 hardest GCSE’s’ ranking chemistry, physics and biology as 7, 8 and 9 respectively. The research shows that the sciences are difficult to learn when compared to other subjects studied at the same level; but why is this the case?

Cognitive demand

In 1956 Benjamin Bloom proposed a hierarchy of educational objectives which ordered cognitive processes from simple to higher order thinking skills (Capel et al, 2009, p. 254). The taxonomic pyramid (Appendix 2) shows knowledge retention as the basic foundation for higher order cognitive ability with analysis, synthesis and evaluation shown as high level skills.

It should be noted that within science, knowledge retention and understanding, although low on the hierarchy, can involve a great deal of information for learners to process. For example when learners start secondary school at 11 years old they are introduced to scientific equipment they have never seen before and have no idea what it is called. Yet they need to be able to recall the name of apparatus and understand their uses within a practical investigation.

Science lessons in many secondary school settings aim to incorporate as much practical as possible in order to meet the requirements of the National Curriculum. This type of investigative learning requires the learners to access and use higher cognitive skills such as analysis and evaluation hence making the requirements of the lesson much more difficult. It is the conclusion and evaluation of investigative work that is the most valuable in assisting pupil progress yet inevitably the most difficult and challenging. From this it is evident that higher order cognitive skills are required and used much more frequently in science than in many other subjects hence making it more difficult.

Jean Piaget’s cognitive development theory (1963) linked a child’s maturation with cognitive ability. Capel et al (2009, p. 254) states:

“ He saw intellectual and moral development as sequential with the child moving through stages of thinking driven by an internal need to understand the world.”

In a secondary school science lesson, based on Piaget's development theory, it would be appropriate for the teacher to assume that the learners would be in one of the final two stages: concrete operational or formal operational. You can see from the diagram in Appendix 3 that the concrete operational phase covers from 7-11 years old and suggests that learners can think logically; at 11 years old they can then apply their ideas to abstract situations and become concerned about the future.

If you were to assume that all learners followed these stages in the rigid format implied, then it would be correct to assume that all learners in a year 7 class would be able to use logical thought processes yet their ability to apply their logic to new abstract situations and make hypothesises would still be quite limited. This causes problems with learning the Key Stage 3 (KS3) science curriculum as it is full of abstract ideas which do not follow the learners logical thought processes. There are more abstract ideas in science than in any other subject and if learners are not yet in the final stages of cognitive development suggested by Piaget, they are going to find the context very difficult indeed.

Learners in the concrete operational stage of development are going to experience barriers to their learning when their logical cognitive abilities are challenged by new abstract ideas. This conflict between different thought processes and accepting that their logical reasoning is in fact incorrect can be damaging and prevent further progress in their immediate learning. It takes time to teach abstract ideas and this is even more of a challenge if your learners do not reach the final stage of development.

Piaget's stages of development are rigid and somewhat flawed when applied to a real classroom setting where you can have 30 year 7 pupils all at varying levels of cognitive ability. Teachers will always have learners in their class who have progressed through the stages very quickly and have their own ideas and thoughts about many different abstract situations. On the other hand there will be pupils in the class who may never fully complete the final stage of development.

The use of correct scientific language is difficult as learners may, through their own life experiences, hold different meanings for scientific words. These are known as heteronyms; words that have a different meaning in one context and then another in a scientific context. These alternative meanings make understanding more difficult, especially for learners where English is not their first language. It also means that learners can struggle to accept the scientific meaning hence making their learning more difficult.

Research carried out in America by Sruggs and Mastropieri (1993 cited by Sullenger, n. d) indicated that over 750 scientific words were introduced from kindergarten through to sixth grade, and the story is no different in Europe. Science is a subject of high cognitive demand; learners will struggle to be successful in the subject if they are unable to access higher thinking and communication skills. If learners lack the vocabulary to share their scientific observations and explain their ideas they are going to underachieve; not through lack of understanding but through poor literacy.

When relating these ideas regarding literacy and language to Piaget's theory it can be noted that learners should be able to use language to represent objects during the pre-operational stage which is experienced from 2-7 years old. The abundance of difficult words used in science means that learners need to have well developed language skills and could experience a setback in their cognitive development. They need to do this whilst teachers are also expecting them to think logically and apply ideas to abstract situations. It is a lot to ask of an 11 year old especially one who is already behind in terms of their cognitive development.

Osborne (1996, p274 cited by Henderson and Wellington, 1998) ‘ says of learning physics that it is:

“ more akin to the learning of a foreign language than it is to the learning of historical facts”. This is equally true of the other sciences’. Everyone it seems considers science to be a practical subject but fail to realise the complexity of the language which needs to be learnt in the first instance.

Orey (2010) discusses the educational implications of Piaget’s theory. They stress the importance of the consistency between the content of the lesson and the developmental stage of the learner. They also state that opportunities should be provided to allow learners of different developmental stages to work together. I have seen this method used in secondary school; it is called ‘ challenge groups’ and works well to allow learners to scaffold each other’s learning. This idea is also given strong focus by the work carried out by Vygotsky.

Vygotsky (1962) believes in the importance of a ‘ Zone of Proximal Development’ (ZPD) in order to develop higher level thinking skills. The ZPD is ‘ the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers’ (Vygotsky, 1978 cited by Chaiklin et al, 2003 p. 39). Please see Appendix 4 for a visual representation of Vygotsky’s theory.

The work of Vygotsky highlighted the importance of talking, and research in the UK has highlighted its importance to learning (Capel, 2009). ‘ Communication is the essence of the socio-cultural experience when students are learning and problem solving. Through language and culture, teachers and students negotiate meaning’ (Connell and Charles, n. d).

Vygotsky strongly believed that talking and socialisation facilitate higher order thinking skills; however the idea of requiring full social interaction in order to learn can become problematic when trying to apply the ideas in the average secondary school science lesson. Group work can easily take place in small, safe classrooms with small class sizes however when there is only one teacher to over 30 learners in a science lab this can become much more difficult. It can become even less practical during experiments and investigations where health and safety is of upmost importance.

It is clear from the analysis of these three different learning theories that the content of the science National Curriculum requires learners to use higher level cognitive skills in order to learn and achieve in the subject. These skills can take a long time to develop and learners need a lot of practice before they become competent high level thinkers and have the language skills necessary to access higher cognitive skills such as analysis and evaluation.

In is also clear that social interaction is very important however in practice it can be limited in a laboratory especially when class sizes are large.

Practical and financial barriers

Based on personal observations, and discussions with staff from various secondary schools, it is clear that some science departments are limited in their delivery of the National Curriculum based on the availability of equipment/ resources and their cost. This can have an impact on the quality of teaching and learning which can take place and therefore support the idea that science is difficult to learn.

It is beneficial for learners to experience science within a laboratory not only for safety and practical reasons but also to help pupils put science into a real-life context and help with understanding of the relevance of the subject. It is not a surprise however that fitting laboratories is very costly as is replacing old equipment and replenishing resources for use in practical investigations.

Laboratories not only require the usual resources provided in a ‘ normal’ classroom such as interactive whiteboards and a teacher computer, which are very costly, they also require specialist desks and stools, an isolated gas, electricity and water supply, fume cupboards and space; space for the equipment, space for the large class sizes and most of all space so learners can work safely.

The question is can learners still experience an outstanding lesson and learn science when not in a laboratory. I would say that a huge amount of appropriate learning can take place outside of the laboratory if good technology is available; however learners need to experience scientific theories in context in order to develop and confirm their own ideas. For example it is very easy to teach the structure of the heart in an ordinary classroom and learners will be able to repeat the knowledge in an exam; but give a learner a heart to dissect and suddenly their understanding is much greater.

Another barrier to learning in science can be the availability of specialist staff such as lab technicians. As with everything extra staff comes at a cost but it is essential to have well trained, experienced technicians if the department is going to deliver science in such a way that is conducive to learning. Technicians are of upmost importance when it comes to delivering practical lessons. Teachers would not be able to deliver their lesson effectively if it was not for the vital support offered by the technicians. If there is not enough money available to employ technicians then there would be a massive impact on learning.

In these times of financial difficulty there needs to be a balance between where cuts are made in order to have the least impact on learning.

A huge barrier to learning can be caused by the teacher themselves. If the teacher lacks confidence in their abilities, has poor subject knowledge and is not effective in their transmission of information then the content of the lesson is going to be even more difficult to learn.

Teaching science is a demanding job with most teachers expected to teach across four disciplines at KS3 (biology, chemistry, physics and earth sciences) and at least 2 disciplines at KS4. To be competent in all these areas and to be competent in their delivery requires great cognitive ability and perseverance.

‘ Effective teachers in the future will need to deal with a climate of continual change’ (McBer, 2000, p. 4). Research carried out by McBer (2000) on behalf of the DfEE found that there were 3 main factors linked to the effectiveness of the teacher which influenced learning and progress: teaching skills, professional characteristics and classroom climate. The research identified that effective teachers use their professional knowledge in order to use appropriate and effective teaching skills effectively and consistently, successfully apply subject knowledge and incorporate the use of the national numeracy and literacy strategies.

It is again made clear from the research that science is a very difficult subject to teach consistently to an outstanding level; made more difficult than other subjects by its diverse nature and large content across the 4 disciplines. This raises the question: is science difficult to learn because of poor teaching, or because the teachers have so much content to cover with potentially little resources at their disposal?

Psycho-social barriers

Due to the continuous variation of social context within a classroom environment learners are ‘ frequently involved in unfamiliar learning situations’ (Boekaerts, 2002). In some learners this creates a sense of challenge; for others it causes uncertainty and some level of distress.

Boekaerts (2002, p. 8) states that:

“ Students try to make sense of novel learning situations by referring to their motivational beliefs. Motivational beliefs refer to the opinions, judgements and values that students hold about objects, events or subject-matter domains”.

The research she carried out found that motivational beliefs can result from a range of different experiences: direct learning, observation, verbal statements by teacher, parents of peers and social comparisons.

As a teacher you can have a vast range of different abilities within your class; ability can have a direct impact on the motivation of the learner. It is quite often found that higher ability students show greater self-motivation to learn than their peers who have special educational needs or struggle with certain subjects.

It is important that as a teacher to know the motivational level of your students and encourage those who lack motivation to be more engaged in the lesson. It is important to know which learners have developed unfavourable motivational beliefs about a topic as this can greatly impact on their learning.

Another barrier which contributes to a lack of motivation is the learner’s perception that the science topic is not of relevance to them. If a learner can see how the topic is of relevance to them or to their future aspirations or even if they just consider it useful they will definitely be more motivated to learn; therefore a teacher must consider the relevance of a topic to their learners and if necessary find an innovative way to make it relevant.

Staver (2007, p17) states:

" Cognitive learning theory emphasizes the importance of learning something new by relating it to things that are already meaningful and familiar. Science teachers must remember that their own intrinsic motivation to learn science is likely not shared by many of their students, whose motivation is more likely activated instrumentally, by connecting science to things that are already familiar and important to them".

It is especially important to motivate females in science as they often find it more difficult to find relevance in the topic especially when studying physics.

It is important that teachers set high expectations for learning as this will directly influence that learning (Staver, 2007). It is important that expectations are high for all students regardless of their gender, background or cognitive ability; special educational needs or gifted and talented.

Part 2: What can Science teachers do to help?

Past surveys have found that ' Some 51% of teenagers think science lessons are boring, confusing or difficult' (BBC News Online, 2005). This view has not changed and research is showing that if anything learners are finding science more difficult and do not recognise its importance or relevance to everyday life.

Today's teenagers are the scientists of tomorrow so things need to change in order to make science more accessible and enjoyable for all.

Lowering the language barrier

The correct and appropriate use of language is important across the curriculum regardless of the subject. In Part One literacy and language were highlighted as a barrier to learning due to the complexities of its use in a scientific context.

Henderson and Wellington (SSR. 1998 p. 35) quote from the science national curriculum:

“ Pupils should be taught to express themselves clearly in both speech and writing and to develop their reading skills. They should be taught to use grammatically correct sentences and to spell and punctuate in order to communicate effectively.”

This was interpreted and adapted by the QCA to state that “ pupils should be taught to use appropriate scientific vocabulary to describe and explain the behaviour of living things, materials, and processes”.

Vygotsky highlights the importance of talking and listening as part of socialisation to facilitate higher order thinking skills. It has been highlighted that it is important to let learners speak not only to the teacher but to each other, and learn through speaking (Henderson and Wellington, 1998).

Learners must be provided with opportunities to communicate and collaborate with their peers in order to explore their own ideas on a certain topic (Henderson and Wellington, 1998) as well as develop their language skills. Discussion-based learning is important in developing the learner not only in a science lesson but also socially. This helps to lower the language barrier as learners gain a lot from their peers who can usually word complex scientific concepts in a simple way a teacher never could.

Some learners will not like this style of teaching and will find it embarrassing to talk to their peers' even if in small groups rather than to the whole class. It is important that the teacher facilitates the discussion and thinks carefully about the groups. It would be useful to group learners based on their abilities as mentioned in Part One using a method observed called ' challenge groups'.

" A great deal of science teaching involves the teacher ' telling' and there is little opportunity for pupil talk. How can we be sure that the class have understood the science if they are given no chance to discuss, exchange ideas, or interpret?" (Henderson and Wellington, 1998 p. 36).

Grouping pupils of varying abilities in order to discuss different scientific concepts helps to scaffold the learning of weaker pupils and secure the knowledge of the more able pupils. It is important that the teacher ensures the correct terminology and language is used which can sometimes be difficult especially in a laboratory where seating arrangements are not always ideal for group/class discussions.

For lower ability groups who struggle with literacy it is important to use other strategies to ensure they are able to fully access the content of the lesson. The teacher could use visual representations of the words in order to assist understanding. They could use diagrams to show methods rather than a list of words if the learners struggle to read and use wordmats and glossaries to help support the learners in their written work and spellings. It is important that the spelling of key terms is addressed consistently and is a cross-curricula responsibility for all staff.

Developing thinking skills

From reading and applying the learning theories in Part One and based on my observation in school it is apparent that many secondary school learners are behind in their cognitive development and will struggle to access higher cognitive skills in lessons.

Focussing on methods to improve critical thinking skills and problem solving skills highlighted by Bloom's Taxonomy is important in order for learners to gain confidence and competence in their scientific knowledge and understanding.

Ideally these skills need to be written within the scheme of work for each topic and the best way to improve these skills is through investigation and problem solving tasks. This can have an impact on lesson time available to cover all of the content but is a crucial factor which needs to be accounted for. Without developing these crucial thinking skills at KS3 learners are going to struggle to access the more demanding content covered at KS4. It would be ideal if these skills were covered across all subjects however different departments may have different delivery techniques which could cause further confusion.

In order to address the development of ' thinking skills' a new initiative emerged in 1995 called Cognitive Acceleration through Science Education (CASE). The intervention was based partly on the theories of Piaget; it was " designed to accelerate development so that pupils progress from concrete thinking to formal operational thinking by the end of the two-year programme" (Jones and Gott 1998). The programme was aimed at year 7 and 8 pupils who were previously identified as vulnerable in terms of cognitive ability.

Please see Appendix 5 which details the five stages of the CASE approach. The stages encourage learners to use discussion to resolve cognitive conflicts and reflect on their own thinking before applying their new ideas to abstract contexts. It is easy to see the influence of Vygotsky as well as Piaget in the application of CASE. A very important part of the intervention is giving learners time to think before they answer. All too often teacher expects an immediate answer therefore not allowing learner's time to process any new information.

The principles of CASE have also seen success in both English and Maths (Angus Council, 2001). The results clearly show an improvement in the attainment of pupils who received CASE intervention however the results also show that females benefit from an earlier intervention than boys (Shayer 1999); this could have huge implications for policy in mixed gender schools.

The fact that this intervention appears to have been used in only the ' core' subjects: science, English and maths, appears to reinforce the view that these subjects are more difficult to learn as they require higher order thinking skills and intervention to achieve them.

Over the past 17 years CASE has helped learners to overcome the demands of the content of the science National Curriculum. In schools where CASE was applied up to 25% higher grades were seen in English, maths and science when compared with non-CASE schools (Shayer 2000).

Conclusion

It is clear that the teaching and learning of science is difficult due to the high cognitive skills which are required in order to understand the subject content and apply knowledge to answer questions on abstract situations. The language skills required in order to access these higher skills in science cause a barrier to learning along with other barriers such as a lack of motivation from learners who cannot see the relevance of science in their everyday lives.

Applying the learning theories of Bloom, Piaget and Vygotsky can help schools to employ strategies to try to overcome these barriers. It is important that interventions such as CASE continue to be used as well as other strategies to encourage the uptake of science based subjects in further education especially by females.

Science is difficult to learn; however this makes the sense of achievement, both as a teacher and a learner, even greater.

Word Count: 3, 999

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Appendix 1: Image taken from http://www. belfasttelegraph. co. uk/news/education/languages-are-the-hardest-gcses-research-finds-13423306. html

Appendix 2: Image taken from http://www. bio. unc. edu/Courses/2009Summer/Biol202/

Appendix 3: Image taken from http://www. learningandteaching. info/learning/piaget. htm

Appendix 4: Image taken from http://cadres. pepperdine. edu/omcadre6/BookProject/vygotsky. htm

Appendix 5: Image taken from http://www. cognitiveacceleration. co. uk/documents/ca_stories /secondary/developing_science_in_KS3. pdf

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Appendix 1

10 hardest GCSEs

1. Latin

2. German

3. Spanish

4. French

5. Statistics

6. Vocational engineering

7. Chemistry

8. Physics

9. Biology

10. IT

Appendix 2

Appendix 3

Stages of Cognitive Development

Stage

Characterised by

Sensori-motor

(Birth-2 yrs)

Differentiates self from objects

Recognises self as agent of action and begins to act intentionally: e. g. pulls a string to set mobile in motion or shakes a rattle to make a noise

Achieves object permanence: realises that things continue to exist even when no longer present to the sense (pace Bishop Berkeley)

Pre-operational

(2-7 years)

Learns to use language and to represent objects by images and words

Thinking is still egocentric: has difficulty taking the viewpoint of others

Classifies objects by a single feature: e. g. groups together all the red blocks regardless of shape or all the square blocks regardless of colour

Concrete operational

(7-11 years)

Can think logically about objects and events

Achieves conservation of number (age 6), mass (age 7), and weight (age 9)

Classifies objects according to several features and can order them in series along a single dimension such as size.

Formal operational

(11 years and up)

Can think logically about abstract propositions and test hypotheses systematically

Becomes concerned with the hypothetical, the future, and ideological problems

Appendix 4

http://cadres. pepperdine. edu/omcadre6/BookProject/images/vyg1. gif