Using retrieval practice as a tool to improve attainment in KS5 Biology

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Abstract

Retrieval practice is the act of recalling previously learned knowledge with little or no support (Jones, 2019). It has been shown to improve the retention of information more so than restudying (Roediger and Karpicke, 2006a). Moreover, it can aid the learning of new content too (Pastötter *et al*., 2011). This study investigated how retrieval practice could be implemented in A-Level Biology lessons, its impact on attainment and students' perceptions. It was found that retrieval practice could be embedded into lessons relatively easily, in a variety of formats such as quizzes and concept mapping. Generally, students were engaged in the activities but some retrieval activities were better suited to certain topics or points in learning. Students completed past exam questions before and after the retrieval practice activities. After retrieval practice, attainment on the exam questions improved for all students. Additionally, students completed a questionnaire investigating their study habits. Results showed that many students use retrieval practice when studying but that they were unaware of the direct and indirect benefits to learning. Furthermore, students were also employing study strategies deemed low utility by the literature. Overall, their perceptions of study strategies and retrieval practice remained unchanged over the course of the investigation.

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Introduction

I am passionate about teaching and have worked tirelessly beginning teaching five years ago to ensure that my lessons are engaging and are structured well to allow students to learn. However, despite my best efforts, it is a common occurrence that students forget vital information from one lesson to the next. Often being utterly convinced that they have never been taught this information before. I imagine that many teachers will also share my deep frustrations with this fact. Initially, I felt that the students' lack of remembering was a reflection of my own teaching. Karpicke and Grimaldi (2012) suggest that many educators also interpret this issue to be caused by a problem with the students' own ability to store information. So, over the last 12 months, I have been exploring strategies to help students to remember information for a prolonged period and be able to recall it. In my efforts to do so, I set up a Twitter account and began 'following' a community of teachers who were also looking to improve their practise and share resources. This is how I initially came across retrieval practice and why began researching it further.

In simple terms, retrieval practice describes the process of actively recalling previously learned information with little or no support. Each time the information is retrieved and an answer is given, it changes the original memory to make it stronger. This means the memory is more easily retrieved the next time that it is required (Jones, 2019). Retrieval practice particularly captured my interest over other currently popular educational practices for two main reasons. Firstly, it is relatively quick and easy to implement into lessons. But most importantly, its use is supported by lots of educational and cognitive psychology research which will be discussed in more detail shortly. At this point, it is important to clarify that my interest in retrieval practice is because of the benefits it has to the learning process. The fact that retrieval practice is relatively easy to implement in lessons is a bonus, which I hope would not be interpreted as laziness. As a teacher, my primary aim is to improve my teaching and pupils learning. That said, I do believe that the techniques used should be effective and not massively increase teacher workload. In my opinion retrieval practice meets both of these criteria (Agarwal and Roediger, 2019).

The use of retrieval practice does require a shift in perspective from teaching students to gain knowledge to teaching students how to retrieve knowledge when required (Karpicke and Grimaldi, 2012). With the move to linear exams, where pupils are assessed at the end of a two-year A-Level or GCSE course, students have a huge amount of content to recall. Given that I teach several exam classes, I am always looking for ways to improve my teaching, help relieve their exam stress and ultimately improve their attainment. I am also regularly asked by parents or guardians at parent's evening '*how can I help my child revise?*'. Alongside this, within my school there is a drive to improve teaching and learning practices and '*provide inspirational teaching*'. Improving retention of knowledge and teaching practices is also important in other educational settings, not only my own. Consequently, I felt that retrieval practice was worth investigating further. Therefore, within the subsequent literature review I aim to explain the following:

1. Retrieval practice and the underpinning theories.
2. The benefits of retrieval practice to teaching and learning.
3. How retrieval practice can be implemented within a biology classroom.

Literature Review

Retrieval Practice

Retrieval practice is the act of recalling previously learned information with little or no support (Jones, 2019). Within the literature, retrieval practice is also referred to as the 'testing effect'. As the name suggests, it is the act of testing one's self after an initial period of study (Gog and Sweller, 2015). This has been noted to improve the long-term retention of information compared to no testing and compared to restudying the same information (Roediger and Karpicke, 2006a). Traditionally testing is deemed 'high stakes' as it is frequently used for assessment purposes. But retrieval practice is more than just a diagnostic instrument to provide evidence that information has been retained. It also allows the information to be recalled more easily and enhances future studying ability (Roediger & Karpicke, 2006a; Soderstrom *et al*., 2016). Given the benefits of retrieval practice to information retention and recall, there is mounting evidence within the literature for it to be used more frequently as a learning tool too (Karpicke, 2012).

The term retrieval practice is more commonly used, compared to the 'testing effect', when referring to its use as a learning tool rather than an assessment tool. Doing so avoids any negative associations with the word 'testing' which can sometimes induce panic amongst students (Minear *et al*., 2018). Retrieval practice is also low stakes, much more varied than traditional testing methods and is purely used as a learning aid (Jones, 2019). This is by no means a new concept, but has been documented in cognitive psychology papers dating back to at least 1890 (James, 1890). Gates (1917) also found evidence that recitation, as he referred to it, improved retention compared to studying alone. This was the case so long as recitation was not introduced too early into the learning process. Having defined retrieval practice and briefly mentioned its positive impact on information retention and recall, the next subsection will consider the theory behind this concept and how it aids memory.

A Theory of Memory and Memory Formation

When considering memory there are several analogies within both educational and psychology literature. Moscovitch (2007), a professor of psychology, likens memory to a book in a library. He states that when looking for a specific book on the shelf where it is believed to be located, and it is not there, then there are two possibilities. It could be that the book is located somewhere else in the library or it has disappeared. Either way, as long as the book cannot be retrieved, one does not know whether it exists. Whilst this analogy is not perfect, it helps to support the idea that one does not know if learning has occurred and a memory exists until that memory has been recovered. Karpicke (2012) reiterates this by stating that we may think that our minds contain some information but the only way to judge whether this is the case is to participate in an act of retrieval. Anecdotally, many will recognise that feeling of self-annoyance when unable to offer a response to a question despite once knowing the answer. This all-too-common feeling is also felt by pupils in school settings.

In contrast to the library analogy, within educational research, knowledge is often likened to a structure within our memory (Karpicke, 2012). Teachers are expected to scaffold students learning thus allowing them to construct their own knowledge. The emphasis is on getting the knowledge into the student and building the structure. Teaching practices often focus on the best ways to help students do this. However, rarely in life is the information retained and repeated exactly as it was taught. And rarely is the information required in the same form as it was taught (Karpicke, 2012). Both in examinations and the real world, the knowledge needs to be retrieved and manipulated to be applied to another situation (Karpicke and Grimaldi, 2012). Teachers need to facilitate a students' ability to do this (Karpicke, 2012). It starts with students being able to retain the information for a prolonged period and then be able to recall it when required. Most current, popular teaching and learning techniques focus on supplying the information to a student in an accessible form, but overlook whether the student can then retrieve it when required (Karpicke and Grimaldi, 2012). Therefore, in my opinion, a teacher's role is not just in imparting knowledge, it is teaching the pupils

how to store and access that knowledge. In order to do so, it is important to have a basic understanding of how memories are made and accessed when needed.

The following paragraph will cover a theoretical framework which aims to explain how long-term memories are made. Atkinson and Shiffrin's (1968) simplistic model suggests that all information or stimuli, be it audio or visual, initially enters the sensory register (SR) (Figure 1). It remains here for an extremely brief period of time. The authors suggest that visual stimuli are only accurately stored in the SR for several hundred milliseconds. At this point information may be lost from the SR for good or it will move towards the short-term store (STS). This is also referred to as the working memory. Information is stored here for noticeably longer than the SR but still a very short time in the grand scheme of things. The authors note that it is difficult to estimate how long information remains in the STS but they suggest that stimuli of the audio-visual-linguistic type remains there for 15-30 seconds. Using rehearsal mechanisms can keep the information in the STS for longer. For example, repeating a telephone number out loud to one's self whilst searching for a pen and paper to write it down. Finally, information can then potentially move to the long-term store (LTS) where it remains relatively permanently but can be modified. Rehearsal of information increases the strength of storage in the LTS otherwise this information may be lost over time. Information that is regularly selected for is maintained in the LTS, as it passes back and forth between the STS and the LTS. This can also allow associated words or knowledge to enter the STS and thus potentiates the memory of those too (Atkinson and Shiffrin, 1968). All of this helps to support the previously noted claims of Roediger and Karpicke (2006a) and Soderstrom *et al.,* (2016) who believe that recall aids the retention of information.

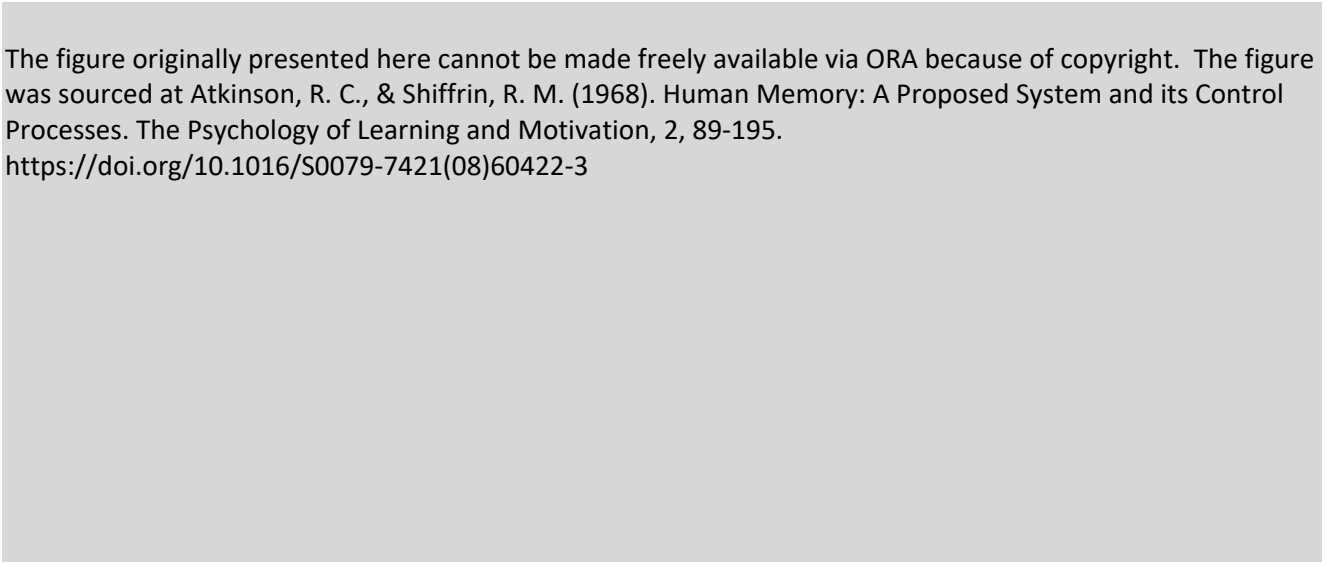


Figure 1. The structure of the memory system (adapted from Atkinson and Shiffrin, 1968)

Atkinson and Shriffin's (1968) model suggesting long term memories decay if not utilised but are strengthened if revisited provides support for similar findings within the literature. One such finding is Ebbinghaus' classic 'forgetting curve' from 1880 and 1885 (Murre and Dros, 2015). Hermann Ebbinghaus was a German psychologist, who conducted well respected experiments to find a relationship between retention of knowledge and the time since the initial learning took place (Murre and Dros, 2015; Jones, 2019). According to Murre and Dros (2015), Ebbinghaus created several lists of thirteen 'non-sense' syllables such as 'KAF' and 'ZOF'. He then practised these lists until he could repeat the series perfectly twice. In later experiments this was reduced to once. The time intervals between learning and relearning the information was: 20 minutes, 1 hour, 9 hours, 1 day, 2 days, 6 days and 31 days (Murre & Dros, 2015). The results from his experiment can be seen in Figure 2. It shows that just 20 minutes after learning material, only 58% of that material is retained. This is shocking from both a teaching and learning perspective. Especially when considering that the pupils in my school have five lessons per day, and are bombarded with information that teachers expect them to absorb and remember immediately. This will be the case in other schools too. Alarmingly, Ebbinghaus shows that only 36% of what a pupil learns at school in the morning is remembered by the time they have their evening meal (Figure 2).

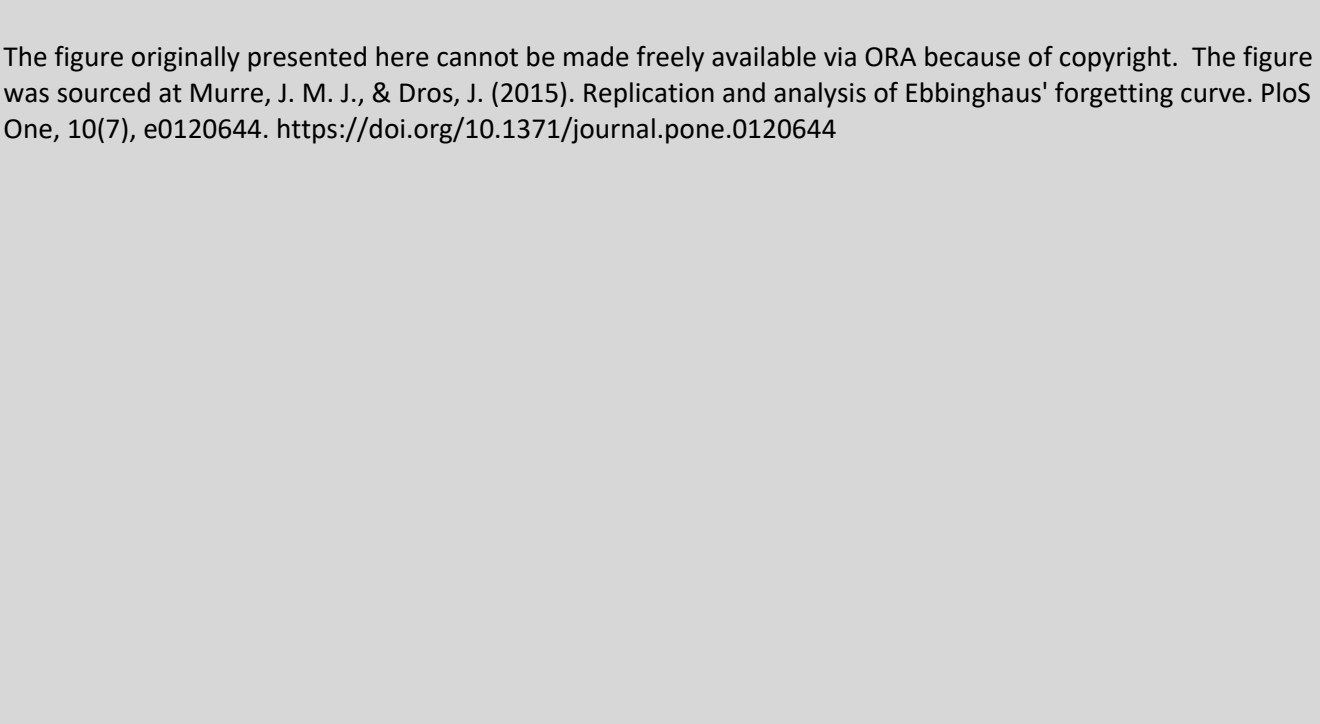


Figure 2. Ebbinghaus' forgetting curve (Ebbinghaus, 1885 as cited in Murre and Dros p.10, 2015*)*

Ebbinghaus' forgetting curve has received criticism within the literature for several reasons. Firstly, his experiments were conducted over 100 years ago and consequently there are some who suggest the curve is now outdated (Roediger, 1985). Secondly, Ebbinghaus was the only subject of his experiments. This brings into question whether the curve can be applied to many different individuals. That said, single subject experiments are not rare within memory psychology research and offer the advantage of no variability between different subjects. However, it does then require many trials for that one subject to ensure reliability. Hence why Ebbinghaus' investigation took seven months to complete (Murre & Dros, 2015). Finally, remembering 'non-sense' syllables with no associated meaning is very different to remembering knowledge in the classroom which does have associated meaning and links with other topics and prior knowledge. With this in mind, there are some who question if Ebbinghaus' curve can be applied to these real-world situations (Roediger, 1985; Murre & Dros, 2015).

In the years since Ebbinghaus, several researchers have attempted to replicate his experiment and his forgetting curve, with varying degrees of success. According to Murre and Dros

(2015), Radossawljewitsch (1907) and Finkenbinder (1913) both succeeded in producing their own forgetting curves. However, their method was somewhat different to Ebbinghaus' method and so not truly able to verify it. More recently Murre and Dros (2015) replicated Ebbinghaus' experiment nearly exactly as some details of the original methodology were not included in his 1880 or 1885 written work. Dros, was both author and subject in this experiment like Ebbinghaus was. Dros also learned lists of nonsense syllables (in Dutch rather than German) and attempted to repeat them at the same time intervals as Ebbinghaus. The forgetting curve Murre and Dros produced shared many characteristics with Ebbinghaus' curve. Murre and Dros (2015) therefore concluded that their results validated the Ebbinghaus forgetting curve.

Ebbinghaus' curve displays mathematically how quickly forgetting occurs. But forgetting is not necessarily an inevitable fate (Murre & Dros, 2015). Even in 1917, Gates stated that recitation improves retention. In 1968, Atkinson and Shiffrin provided a theoretical model demonstrating how memories form and highlighting that rehearsal of information stored in the LTS acts to increase the strength of storage of that information. Kang *et al.,* (2014) put that theory to the test when they conducted an experiment whereby subjects were presented with 60 Japanese-English word pairs to learn. Participants were then challenged with retrieval practice of these words on three occasions over the next 28 days. Results from their experiments were presented graphically and show that their ability to recall pairs initially fell in line with Ebbinghaus' curve. But, with regular retrieval the amount of information retained increased. Participants were able to 'overcome' the forgetting curve as the proportion of pairs they could recall remained high and did not decline as quickly compared to the Ebbinghaus' forgetting curve (Murre & Dros, 2015).

This initial section of the literature review has defined the term 'retrieval practice' and explained how it is thought to aid memory. Retrieval practice is widely accepted as a low-stakes learning tool that requires users to regularly recall information that they have previously learned (Gog & Sweller, 2015). Doing so aids the learning and retention of that information (Roediger & Karpicke, 2006a). Atkinson and Shiffrin's 1968 model of memory formation describes how long-term

memories can form but that the strength of those memories can be affected by how regularly they are accessed. The Ebbinghaus forgetting curve provided quite a stark image of how quickly memories can fade without regular recall (Murre & Dros, 2015). Nevertheless, experiments by Kang *et al.,* (2014) show that the forgetting curve is not an inevitable fate. The next section of this literature review will explore some evidence which supports the use of retrieval practice in the teaching and learning process.

The Benefits of Retrieval Practice to Teaching and Learning

This section of the literature review will explore how retrieval practice can benefit the teaching and learning process. Roediger and Karpicke (2006a) propose that retrieval practice is good for three purposes: assessment, retention of new information that has just been taught and retention of future information that has not yet been taught. It is the benefits to retention that are of interest in this investigation. Retrieval practice improves long term retention of information over restudying information. This conclusion is based upon findings from multiple different experiments. One such example comes from Roediger and Karpicke (2006b). They conducted an experiment using 188 undergraduate students who studied short prose passages covering general scientific topics. Participants were split into three groups and given one of two possible passages of text to study. Depending on the group, participants either studied the passage four times and took no recall tests (SSSS), studied it three times and took one recall test (SSST), or studied it once and took three recall tests (STTT). Study periods were five minutes long and participants had to record how many times they read the text during this time. In the test phases, participants were given a blank piece of paper and were instructed to recall what they remembered in a 10-minute test period. This was phase one of the investigation. Then, for phase two, 99 participants took a final recall test five minutes after completing phase one and 90 participants took a final recall test one week later. Within the five-minute test group, the SSSS group of participants could recall 83% of the text compared to the STTT group who could only recall 71%. However, on the test delivered one week later, those in the STTT group recalled 61% compared to SSSS group who recalled 40%. The authors concluded that retrieval

practice (in the form of testing) allowed better performance on delayed tests and contributed to better long-term retention.

Results from Roediger and Karpicke's (2006b) study are interesting as they provide quantitative evidence for the amount of information retained due to retrieval practice. As the participants studied text which was related to science, it is also more applicable to what happens within my classroom environment compared to the Kang *et al*., (2014) paper which looks at the retention of lists of Japanese-English word pairs. Nevertheless, the amount of text to be recalled was short (256 or 275 words depending on which passage was assigned) and subjects were asked to recall the ideas from it. This is unlike what usually happens within a secondary school environment. In schools, information usually has to be recalled and then applied to a question, rather than recalled 'parrot fashion' as seemed to be the case in the Roediger and Karpicke's (2006b) study (Karpicke, 2012). Also, over a two-year A-Level course, there is far more information to be retained than approximately 300 words. That said, the findings give clear evidence for the benefits of retrieval practice over restudy for long term retention of information. But there may be some who argue these findings are not fully transferable to the school classroom. This is because the investigation does not replicate normal practice in a school setting and the participants were undergraduate students rather than secondary school students.

Some researchers within the cognitive psychology field have taken Roediger and Karpicke's (2006b) evidence that retrieval practice is more beneficial for the long-term retention of information compared to restudy one step further. They are investigating whether the time between retrieval attempts impacts learning. This is known as spaced retrieval (Kang *et al*., 2014). In spaced retrieval the information is regularly reviewed at either equal time intervals or non-equal time intervals after the initial learning episode (Karpicke and Roediger, 2006b; Karpicke and Roediger, 2007). Landauer and Bjork (1978) were the first to compare the effectiveness of these two types of spacing. One of their experiments involved asking 468 university students to remember first name and last name pairs. Participants were given one study period in which to learn the pairings and were then split into

several groups. Each group had a different schedule for practicing the pairings, for example: equal interval, massed, expanding and contracting. The massed practice group had three consecutive attempts to remember the correct last name when given a first name, whereas the other groups had space between their practice attempts. On the final test which was delivered shortly after the final practice attempt, the group with the expanding spaced practice had the highest recall, followed by equal, contracting and massed respectively. Bjork (1999) believes that expanding retrieval practice works well as it creates, what he termed, 'desirable difficulties'. That is, more effort is required from the student in order to recall the previously learned information. Doing so strengthens the memory and the individual is more likely to remember it in the future. It also stands to reason that since the rate of forgetting is so rapid initially it would be more advantageous to do more retrieval earlier compared to later (Ebbinghaus, 1885).

Nevertheless, there is conflicting research within the literature, as there are groups of researchers who believe that equally spaced retrieval practice is more beneficial (Logan and Balota, 2008). Karpicke and Roediger (2007) replicated Landauer and Bjork's (1978) findings for an immediate final test but found that equal-interval retrieval practice yielded better results on a delayed final test. They claimed that the position of the first retrieval attempt is more important than whether the retrieval is equally spaced or expanding. They too agreed that the retrieval had to provide 'desirable difficulties'. There are several limitations to the aforementioned experiments. For example, they were designed with one single final test to determine how much information was retained. Investigations were also conducted over a short time period of a couple of days. Whereas in real life, learned information has to be retained for much longer and accessible more than just once (Kang *et al*., 2014). Judging by the papers I have read, there are lots of findings which are still inconclusive. Nonetheless, it is interesting how spacing appears to benefit the learning process in different ways. Delving too deep into the spacing of retrieval practice is however, beyond the scope of this investigation.

Having discussed how retrieval practice benefits long term retention compared to restudy, the following paragraphs will describe research exploring how retrieval practice can benefit the retention of material that is yet to be studied (Pastötter *et al.,* 2011). Pastötter *et al*., (2011) used electroencephalograms (EEG) to measure the electrical activity of the brain during retrieval activities. Since electrical signalling within the brain is vital in thought and memory, studying these signals has become increasingly popular (Sederberg *et al*., 2006). During an EEG, small sensors are attached to a person's scalp to measure the electrical activity generated in response to stimuli in the central nervous system. The electrical activity can be measured and is split into different frequency groups such as theta, alpha and beta (Pastötter *et al*., 2011). In the research conducted by Pastötter *et al.,* (2011), participants studied five lists containing 20 items and were asked to remember all of the items on the lists for a final recall test. Participants were divided into five groups. Three of these groups were classed as retrieval groups but each different group completed different retrieval tasks. For example, one group was tested immediately on lists one to four, another group did a semantic generation task whilst the third group did a memory task after being exposed to each list. The idea behind these retrieval groups was that completing retrieval activities in between each list would improve list segregation. That is that items from list one were not confused with items from another list. There were also two non-retrieval groups. One of these groups was allowed to restudy the lists of words whilst the other group had to complete a distractor task. All of the participants were tested immediately for list five. The lists each contained 20 unrelated German nouns which were chosen at random and the lists were also assigned to each participant at random. Participants were shown the words individually initially and then presented with the entire list for one minute. During the testing phase, participants had one minute to write down as many words as possible from the lists that they had studied. They were provided with different sheets of paper for the different lists.

Pastötter *et al.,* (2011) found that testing and retrieval allowed more recall than the non-retrieval groups. It also allowed more list segregation. It is thought that this increased retrieval and list segregation is because retrieval during learning causes a change in context between the single

lists so each list has its own cues for memory. EEGs of all participants were recorded during the study of the five lists and compared. It was noted that there was an increase in alpha frequency waves in the non-retrieval groups where lists of words were not very successfully segregated. There were no increases in alpha frequency from list one to five in the retrieval groups (Pastötter *et al*., 2011). In previous studies, by different research groups, high levels of alpha frequency were linked to poor recall and low levels of alpha frequency were linked to good recall. High levels of alpha frequency have been associated with 'inattentional encoding' (Sederberg *et al*., 2006; Pastötter *et al.,* 2008). This means attempting to form memories without the individual being fully focussed. It is proposed that retrieval during the learning process removes the 'inattentional encoding' by acting as a 'reset'. Thus, the learning of the later lists is just as effective as the learning of the earlier lists (Pastötter *et al*., 2011). Therefore, an important benefit of retrieval practice is to create a break in knowledge just learned so that the brain is ready to accept new information.

As previously discussed, successful retrieval practice (i.e. recalling an answer correctly) has been noted to improve long term retention as well as improve the learning of new information (Roediger and Karpicke, 2006b; Pastötter *et al*., 2011). Within the literature, these are referred to as the direct effects of retrieval practice (Karpicke and Grimaldi, 2012). But retrieval practice also has some indirect effects on the teaching and learning process. For example, regular testing of subject content often, but not always, means that students are revising material fairly frequently. This gives students more opportunity to learn the information (Roediger and Karpicke, 2006a). Although, as Roediger and Karpicke (2006b) showed, restudy is not as effective as retrieval. Frequent re-study prevents students 'cramming' prior to an examination (Roediger and Karpicke, 2006a). Even unsuccessful retrieval practice (i.e. recalling an incorrect answer) can benefit the teaching and learning process as the individual can gain feedback on what they do not yet know and then focus their learning on that area (Karpicke, 2012). Using retrieval practice to guide future study links to metacognitive awareness. It is a different technique compared to using retrieval practice to enhance learning ability, which would be a direct effect of retrieval practice (Karpicke *et al*., 2009). Given both

the direct and indirect effects of retrieval practice to the teaching and learning process, this led me to wonder if the students themselves know of the benefits.

Student Awareness of the Benefits of Retrieval Practice

This section explores whether students themselves are aware of how retrieval practice benefit them and whether students are employing this technique. In Roediger and Karpicke's (2006b) study, participants were given a questionnaire to complete regarding how confident they were at remembering information after a period of retrieval or restudy. To briefly summarise the investigation again, participants were asked to read and remember a passage of text. Some participants studied the text four times (SSSS), another group studied the text three times and undertook retrieval once (SSST) and the third group studied the text once and undertook three retrieval attempts (STTT). Approximately half of the participants across the three groups took a final recall test five minutes after this with the other half taking the final recall test one week later.

The aforementioned questionnaire contained three questions; one of which was how well did the participants think they would remember the passage after one week. The SSSS groups were overall more confident in their ability to remember the passage than those in the SSST or STTT groups. This confidence was not reflected in the final results after a week as the STTT group recalled 61% compared to the SSSS group who recalled 40%. The authors commented that repeated studying 'inflated students' confidence'. Although repeated studying produced short term results, it did not help long term retention (Roediger and Karpicke, 2006b). Possible explanations for this include metacognitive illusion (Bjork *et al*., 2013). Whereby ineffective learning strategies, such a re-reading, caused participants to make incorrect judgements about what they knew (Tai *et al*., 2018). Karpicke *et al*., (2009) believe that this is because when students continually re-read the same information, they start to read it with more fluency each time. This gives them an overconfidence in their judgments of the amount they have retained.

Following those student opinions, Karpicke *et al*., (2009) conducted research with the aim of discovering undergraduate student study strategies. The rationale behind this was that there was

mounting evidence within the literature for the advantages of retrieval practice but a lack of awareness amongst the students it would benefit (Dunlosky *et al*., 2013). The questionnaire in the Karpicke *et al*., (2009) study asked '*what kind of strategies do you use when studying?*'. Results showed that 84% of participants re-read notes, with 55% stating that it was their number one strategy. Only 11% of participants reported that they use retrieval practice whilst studying. Participants were then given a scenario whereby they were studying for an exam and after reading the chapter one time they have to choose one of the following options. Option A was to restudy the chapter, option B was to recall the material without restudy (retrieval practice) and option C was some other study technique. Only 18% of participants indicated that they would use retrieval practice (option B). Of these participants, their reasoning was to guide future study rather than use it as a learning tool. Guiding study is an indirect benefit of retrieval practice and indicates most of the participants were unaware of the direct benefits of retrieval practice (Karpicke *et al*., 2009). This lack of understanding for the benefits of retrieval practice has serious implications for students' study habits. As Roediger and Karpicke (2006b) note, students who prefer to re-read notes may fall prey to believing they know the material better than they actually do.

Cervin-Ellqvist *et al*., (2020) also conducted a similar questionnaire to Karpicke *et al*., (2009) but this time on undergraduate engineering students. In their questionnaire, participants again listed the common study strategies that they use. These included re-reading, highlighting notes and testing. In Cervin-Ellqvist *et al*., (2020)'s study, 83.2% of students studied using past exams. The explanation for this included to see how the paper was structured and what type of questions might come up. Only about 10% of those students used it for metacognitive purposes to evaluate their own understanding and direct future study. No one reasoned that the act of self-testing (or retrieval) improves learning, again indicating a lack of awareness of the direct effects of retrieval practice (Pastötter *et al.,* 2011). When rating the effectiveness of strategies, 63% of students found that testing was more effective than re-reading (Cervin-Ellqvist *et al*., 2020). The difference in results could be for many reasons, including the educational practices differing between Scandinavia or the

USA. Or perhaps over the 11 years since the Karpicke *et al*., (2009) study there has been more focus on helping students learn how to study in an effective manner.

This section of the literature review explored the direct and indirect benefits of retrieval practice (Roediger and Karpicke, 2006a; Karpicke and Grimaldi, 2012). It also provided evidence to suggest that retrieval practice of information improves retention compared to restudying (Roediger and Karpicke, 2006b). Additionally, retrieval practice can aid the learning of new information (Pastötter *et al.,* 2011). This section also revealed the study strategies employed by students and whether students were aware of how retrieval practice would benefit them (Roediger and Karpicke, 2006b). The next part of this literature review will discuss how retrieval practice can be implemented into the classroom environment.

Implementing Retrieval Practice in the Classroom

Given how useful retrieval practice is to the teaching and learning process, it is important to know how it can be implemented effectively within the classroom. Agarwal *et al.,* (2021) note that researchers are increasingly encouraging teachers to use retrieval practice in the classroom to benefit student learning. I have found this myself as more information on retrieval practice is becoming easier to access for the average teacher. For example, information is readily accessible on twitter or in easy-to-read informative books which summarise the research. As such, many teachers are now implementing retrieval practice in a variety of ways such as multiple-choice quizzes, free recall such as concept mapping and short answer response questions. The aim for this section is to discover how to implement retrieval practice and whether some methods of retrieval are more effective than others.

Smith and Karpicke (2014) conducted research to the most effective ways of implementing retrieval practice for long term learning. They investigated the use of short response questions and multiple-choice questions (MCQ) as they identified these as being the most popular formats used by teachers. Both short response questions and MCQ can be used for testing basic recall as well as higher order application questions. MCQ are advantageous as they are quicker and easier to mark

than short response questions. But they also expose pupils to wrong answers which the pupil may learn incorrectly unless feedback is given (Roediger and Marsh, 2005; Butler *et al*., 2006). Equally, short response answers may provide students with the 'desirable difficulties' needed to ensure effective learning (Bjork, 1999). In experiments conducted by Smith and Karpicke (2014), participants were exposed to four texts of between 500-600 words. Each text was split into four paragraphs. Participants were given an initial study period of five minutes to read the four texts and complete the initial retrieval practice. They were then split into different retrieval groups and faced either short answer questions, MCQ, or a hybrid of both. The questions asked of participants were a mix of direct recall and application questions. Response times were measured for each question as an indication of how difficult the participant found the question. After one week the participants returned to complete a final short answer response test.

Results from this aforementioned study showed that the initial retrieval format did not matter. There was no statistical difference in the final test score achieved by the different groups. It was noted that the participants found the short answer responses more difficult as indicated by longer response time. Though this did not affect the final outcome. The findings indicate that retrieval is effective and of the techniques investigated, one form of retrieval is no better than another. That said, these investigations took place over a short time frame, with relatively little content compared to a secondary school syllabus. It also took place in laboratory conditions where more variables are controlled and the type of learner is less diverse than in a typical school setting.

Agarwal *et al.,* (2021) also raised this concern. These authors felt that techniques which were successful in the laboratory would not necessarily be successful in a classroom environment with more variables to contend with. Therefore, they conducted a meta-analysis with a strict set of criteria. From their literature search on retrieval practice (and various other associated terms), 1810 papers were initially screened. Papers were then excluded if they involved online studies, laboratory studies or collaborative retrieval practice. Agarwal *et al.,* (2021) also specified that the retrieval practice had to be low stakes and it could not form part of any assessment process. Ultimately, 50

experiments from 37 studies were included. These studies came from a range of countries, sample sizes, education levels and time between retrieval practice and final tests. Through their analyses, Agarwal *et al.,* (2021) concluded that retrieval practice still had benefits to learning even when conducted in the classroom. They advised that retrieval practice should be implemented without worrying about the format or the timing of the retrieval. Retrieval practice was found to have a wide range of benefits compared to other class activities and lessons without retrieval.

Concept mapping is another retrieval tool mentioned by the literature. This involves the student graphically illustrating their knowledge on a piece of paper (for example, using a spider diagram). It tests the recall of their knowledge and allows them to organise it by forming links with other topics and ideas (Francis *et al*., 2020). Concept mapping works especially well if it is free recall and notes are not used (Blunt and Karpicke, 2014). Carpenter (2009) suggests that this is because the student has to create connections between the information and in doing so this helps to improve how they retain the information. The authors conclude that concept mapping may be useful especially to those with less prior knowledge as it helps the individual to make connections thus assisting them to retrieve information in future.

Agarwal *et al.,* (2021) state that any form of retrieval is better than no retrieval. In addition to the MCQ and concept mapping previously mentioned, there are lots of strategies that many teachers already use in the classroom that are deemed effective retrieval practice. For example, closed book short answer questioning or quizzes. Agarwal and Roediger (2019) suggest that teachers simply need to be made more aware of how, what they already do, is benefitting the pupils that they teach. Furthermore, small, non-time-consuming tweaks to existing lesson activities would also allow teachers to implement more retrieval practice into lessons without any additional planning or lesson time being taken up. One such example could be in lesson starters. Often teachers begin a lesson by discussing what prior learning took place. Instead, this could be altered to asked the students what they learned last lesson. Agarwal and Roediger (2019) also suggest modifying how 'Think-Pair-Share' activities are used. Typically, 'Think-Pair-Share' activities involve a teacher posing a question to the

class and then giving pupils time to think about an answer individually. Pupils are then instructed to discuss the question and answer with a partner before finally sharing the answer as part of a whole class discussion. In some settings it is difficult to know whether a student is actively taking part in this activity or having an informal chat with friends. Therefore, Agarwal and Roediger (2019) propose that a small tweak could be to get the students to write a response down. Even if it is written on a scrap piece of paper and not marked, the teacher can see that every student is writing something down, and thus engaging in low stakes retrieval. The feedback could involve the whole class, as would normally happen in the final stage of 'Think-Pair-Share'. Therefore, implementing retrieval practice can be relatively easy and can involve making only minor adjustments to current teaching practices.

Summary of Literature Review

This literature review has shown that memory formation is elastic and one cannot truly know if they have remembered something until they test for it (Moscovitch, 2007). Atkinson and Shriffin's (1968) theoretical model explains that information is retained in the STS for 15-30 seconds but rehearsal of this information can allow that information to move to the LTS where it is more likely to remain. Ebbinghaus' curve is a sharp reminder that information can be lost very quickly but through retrieval practice the amount of information retained can be improved (Murre and Dros, 2015). It is thought that this is because retrieving the information creates more cues and pathways to access that memory. Retrieval practice also hold pupils accountable and produces less metacognitive illusion than restudying. Several studies have shown that retrieval does produce better long-term retention than restudying (Roediger and Karpicke, 2006b; Bjork *et al*., 2013). Other direct benefits include improved learning of new material (Pastötter *et al.,* 2011). There are also indirect benefits of retrieval practice such as directing future study and gaining feedback from teachers to improve understanding (Karpicke and Grimaldi, 2012).

As mentioned previously, my frustration developed when my students were continually forgetting information that I had spent hours planning and teaching them. However, after much

research my frustration turned to focus on how I can best help them to retain and recall more knowledge. It is also clear that students are unaware of how to study effectively (Roediger and Karpicke, 2006b; Dunlosky *et al*., 2013). I feel very deeply that knowledge gained through this literature review should be shared with my students, their parents and other educators within my school and beyond. Students should be aware of what study techniques are effective and why some are more effective than others. Teachers should also be aware of this and feel confident to implement retrieval practice in a way that fits into their lesson and does not increase their workload.

The following research investigation into retrieval practice will focus on my A-Level biology group. Due to the pandemic, these students will be taking their first set of external exams in June 2022. Since they will have never undertaken a large number of external exams in various subjects before, I think it is important that they are exposed to the research surrounding effective study techniques. I also think that it would be interesting to find out what they currently use to revise. So given my findings for this literature review, the objectives of this study are to:

(a) investigate how retrieval practice can be embedded into A-Level Biology lessons,

(b) measure the impact of retrieval practice on attainment in A-Level Biology lessons,

(c) investigate student perceptions of how retrieval practice has impacted their learning.

Methodology

This methodology section provides an account of the steps taken to address each research question. It describes how data was collected and analysed alongside justifications for these actions. In addition, it describes the nature of the participants and the ethical issues that were considered. Furthermore, it outlines how the collaboration with other staff members occurred.

Research Questions

As a result of the literature review and my own interests in retrieval practice, the following are the research questions which will be addressed in this investigation:

1. How can retrieval practice be embedded into A-Level Biology lessons?
2. What is the impact of retrieval practice on attainment in A-Level Biology lessons?
3. What are student perceptions of how retrieval practice has impacted their learning?

Overview of Methodology and Data Analysis

Table 1 summarises the instruments used to address each research question (RQ) alongside how the data was subsequently analysed. The methods of data collection will be discussed in more detail throughout this methodology section. The data analysis is more thoroughly explained within the findings and discussion section.

Table 1

A table showing the methods of data collection and analysis for each research question

Research question	Methods of data collection	Data analysis approaches
1. How can retrieval practice be embedded into A-Level Biology lessons?	Low stakes quizzing, retrieval ticket and concept mapping.	Analyse written responses to retrieval activities and participation.
2. What is the impact of retrieval practice on attainment in A-Level Biology lessons?	Past paper exam questions (pre-RP and post-RP).	Compare pre-RP and post-RP attainment.
3. What are student perceptions of how retrieval practice has impacted their learning?	Questionnaire (pre-RP and post-RP)	Analysis of written responses pre-RP and post-RP. Compare student rankings of strategies.

Participants

This investigation was conducted in March 2022 with the Year 13 A-Level Biology students whom I teach. There were 21 students who took part; ten males and eleven females aged between 17 and 18 years old at the time of this research. Two of the males are classed as EAL but their English is very strong. Three students have a diagnosis of dyslexia and require 25% extra time for assessments. None of the students are classed as vulnerable. They were recruited during lesson time but were free to choose whether they participated in the investigation. The ethical considerations surrounding the participants and their participation will be discussed further on within this methodology section.

Study Design and Data Collection

This section of the methodology will describe the steps taken in this investigation and the rationale behind them. Table 2 outlines the events that took place over four lessons in order to gather data to address each RQ. As RQ2 and RQ3 measured potential changes in attainment and perceptions, pre-retrieval practice (pre-RP) and post-retrieval practice (post-RP) test instruments

were used. Because of this, the pre-RP elements of the investigation were set up prior to addressing RQ1. Therefore, the method will be recounted in the chronological order in which the steps took place.

Table 2

A table outlining the investigation

Lesson	Data collection	Topic taught	Retrieval practice opportunity
Lesson One	Pre-RP questionnaire and pre-RP completion of past exam questions	Monohybrid inheritance	Retrieval reflection ticket
Lesson Two	Kahoot quiz participation	Dihybrid inheritance	Kahoot quiz on keywords
Lesson Three	Concept mapping responses	Hard-Weinberg equation	Concept mapping
Lesson Four	Post-RP questionnaire and post-RP completion of past exam questions		

During lesson one participants were asked to complete a questionnaire (Appendix A). This was in order to address RQ3 which sought to discover how participants perceived their learning had been impacted by retrieval practice. Therefore, this was the pre-RP questionnaire with the same questionnaire also completed at the end of the investigation and referred to as the post-RP questionnaire. A questionnaire was chosen over other test instruments such as interviews, as questionnaires allow data to be collected and analysed quickly (Firth, 2020 p157). Although interviews are more useful in allowing comments to be clarified and explained further, they are more time consuming. This is because they require the researcher and the participant to conduct the interview outside of class time. Finding a time to suit both the pupil and the researcher is difficult to organise, especially when the researcher is also the class teacher (Thomas, 2017 p202).

The questionnaire used in this investigation was adapted from Cervin-Ellqvist *et al*., (2020) and it was picked for several reasons. Firstly, both Karpicke *et al*., (2009) and Cervin-Ellqvist *et al*., (2020) suggest that students are using ineffective study techniques and are not aware of the direct benefits of retrieval practice. It was my wish to find out whether my students were in a similar position and then whether their opinion changed following my investigation and use of different retrieval practice techniques. Secondly, the questions were relatively open and allowed participants to freely respond by listing, ranking and justifying the popular study techniques that they use. In the original questionnaire, the third question asked participants to rate the 'effectiveness' of each strategy on a six-point Likert scale. However, following discussion with my supervisor, we felt that the questionnaire should be altered slightly to prevent over complicating matters for participants. The wording was changed to 'helpful' rather than 'effectiveness' and the Likert scale was reduced to a three-point scale. Participants also had a box to write any additional comments if they wished. This questionnaire was also relatively short which has been noted to increase response rate and validity. This is because it prevents the participant becoming 'bored' and so increases the likelihood that all participants complete the questionnaire, rather than just the conscientious ones (Firth, 2020 p162). To analyse data from this questionnaire, pre-RP and post-RP responses were compared. Additionally, the number and type of strategies used pre-RP and post-RP were compared. A more detailed description of the data analysis can be found in the findings and discussion section.

To address the impact of retrieval practice on attainment in A-Level Biology lessons (RQ2), participants were presented with some past exam questions covering the topic of genetics and inheritance (Appendix B). Participants had previously been taught this topic in October 2021 so all had prior knowledge of the topic. But when participants were presented with the past exam questions in lesson one as part of this investigation, it was in March 2022. No revision of this topic had taken place in class time since initially covering the topic a few months prior. The past paper questions were carefully chosen so that participants had not previously received these questions in class. The past paper questions were also from very old past exam papers so were difficult to access

online. As far as I am aware, no participants had encountered these questions before. Participants were asked to complete the questions individually. There were 22 marks available and they were given 20 minutes to complete the questions. Those with a diagnosis of dyslexia, who are entitled to extra time, were able to have that extra time if they required it. All of the participants completed the questions in the time allowed. Some participants mentioned that they could not remember how to answer some questions. They were encouraged to try and complete the questions and if they could not answer a particular question then to leave it blank. Participants were required to put their name on the question paper so that their first attempt (pre-RP) could be compared to their second attempt (post-RP) during lesson four. The average attainment for pre-RP and post-RP was calculated along with the standard deviation to identify if there was any significant difference between the two results. Details of how participant identity was protected for this investigation are noted further on.

Once the pre-RP questionnaire and pre-RP past exam questions were complete there were about 30 minutes of lesson one left. Therefore, I began addressing RQ1: *How can retrieval practice be embedded into A Level Biology lessons?* The topic of mono-hybrid inheritance was re-taught to participants and they looked at worked examples of questions. Mono-hybrid inheritance was one of the topics assessed in the past exam questions given to participants. Just before the end of the lesson, participants were asked to complete a retrieval reflection ticket as an exit ticket activity (Appendix C). The retrieval reflection ticket asked participants to note down which areas covered by the exam questions they were confident in recalling and which areas they felt that they had gaps in their knowledge. All participants completed this retrieval activity. The inspiration for the retrieval reflection ticket came from Katie Jones' (2021) book entitled *Retrieval Practice: Resource Guide*. This activity was chosen because at this stage it was important to reflect upon what participants felt they knew and did not know. I also thought it would also be useful for me to know at this stage what they could not remember. This meant subsequent lessons could be tailored to their needs and the retrieval questions adapted to create the most benefit to participants.

In the second lesson participants completed a low stakes 'Kahoot' quiz online using their mobile telephones to answer. Examples of the types of question asked can be seen in Appendix D. There were 15 multiple choice questions on this quiz which I wrote myself. This is something that I would usually do as a teacher. This method of retrieval practice was selected as it is low stakes. Participants were assigned random names so that neither I nor other participants could tell who got which answer right or wrong. Answering quiz questions anonymously was good for the purpose of retrieval whereby assessing how much each participant knows was not important. The purpose was to ensure that participants were practising retrieval. It was also hoped that anonymity would encourage participants to not be embarrassed if they were unsure and at least attempt an answer. The disadvantage to this method was that it required the use of an internet connection and some participants did not have this so had to share devices or not participate. That said, participants could still read the question and see the answers so they could partake mentally. They were encouraged by me to do this, but there is no way of evidencing that they actually did. In the main body of the lesson, more of the A-Level course content was revisited with the participants and they practiced some exam-style questions. It is important to note that these exam-style questions were different to those past paper questions given at the start of lesson one. Feedback was given on these exam-style questions and participants had the opportunity to ask for help if they needed it.

In the third lesson, the Hardy-Weinberg equation was retaught to participants. As a class we practiced some exam-style questions together. Participants were also given time to practice some more exam-style questions individually and again, they could receive help if needed. In the final fifteen minutes of the lesson, participants completed a concept mapping activity in pairs with the person that they were sat next to. The concept map activity can be seen in Appendix E. The concept map was chosen as it was a good way for participants to recall and summarise everything that had been covered in the previous lessons. I felt that working in pairs would also help to encourage retrieval. Responses from the concept map were analysed by thematic analysis. This is further explained in the findings and discussion section. In lesson 4, participants completed the same past

paper questions again (post-RP) and the same questionnaire (post-RP). The past exam questions (pre-RP and post-RP) were then marked by myself, using the mark scheme, to get two scores for each pupil.

Collaboration

All of the resources that were created were shared within my department. Once written online, the Kahoot quiz was visible to anyone who uses the website. The link was also shared with the other two teachers within my department who teach A-Level Biology. The retrieval reflection ticket and the concept mapping sheet was also shared with them. One teacher allowed her class to do the concept mapping as an open book activity which lasted the whole lesson. She chose to do this despite my explanation that this is a more beneficial activity if notes are not used (Blunt and Karpicke, 2014). However, she had the right to exercise her professional judgment and use the resources in the way she wished. That same teacher did not use the retrieval reflection ticket with her A-Level class but instead used it with her Year Seven class. She commented that '*it was really helpful to inform me of what my students knew/didn't know. It's also interesting as some of the things I thought that the kids got appeared in the 'what I need to know more of' section*'. The retrieval reflection ticket, although not an original idea of mine, was also shared on our teaching and learning Google classroom page (with the appropriate credit to Jones (2021)). This is a shared, online workspace for all teachers in my school to access and share helpful teaching and learning resources. The newly appointed head of teaching and learning is very keen to encourage more retrieval practice within the school and has shared lots of resources on this page. However, I am unsure if anyone has accessed or used the resources that I have shared.

I chose to collaborate with colleagues in my department by sharing resources for several reasons. Firstly, I wished to gain feedback on how other teachers may use them in class and how they and their students responded to them. Secondly, there is only one other Year 13 A-Level class. It was taught by my two other departmental colleagues and there were only five students in that

class. Given the differences in how retrieval practice could have been embedded in that class compared to my class, and the difference in class size, I felt that the two experiences would not be comparable. And as such, any data collected from the two classes could not be included together in a meaningful way. In addition to sharing resources with colleagues, I also discussed the findings of this investigation with them. Some responses will be included in the conclusion section.

Ethics

There were a number of ethical issues to consider, given that this research included human participants who were also own students.

Obtaining Consent

To ensure that the research project was compliant with the Ethical Guidelines for Educational Research (BERA, 2018), the project plans were submitted to the University of Oxford's Central University Research Ethics Committee (CUREC) in October 2021. The project was subsequently approved by CUREC at the end of October 2021. Following this, a letter requesting consent to undertake the research project in school was sent to the Head Teacher (Appendix F). Consent was obtained from the Head Teacher in December 2021 (Appendix G). Given that this research project fell within the modus operandi, no signed consent was required from parents.

At the start of the research project, participants were informed of: the purpose of the research, the tasks that participants would complete and what would happen to the data that was collected. In line with the good practice of voluntary informed consent, participants were made aware that it was not compulsory to participate and that they had the right to withdraw themselves from the research at any point without reason (BERA, 2018). I am aware that some individuals are classed as vulnerable and may not be able to give informed consent (Farrimond, 2017). However, none of the participants in this study are classed as vulnerable.

Farrimond (2017) makes an excellent point regarding 'informed consent' and 'right to withdraw' when the participants are the researchers own students (as was the case here). She states that students may feel obliged to take part in the research especially if the research activities are

taking place during lesson time and are therefore already built into the lesson plan. Naively, this was something that I initially had not considered in my original plans. So, when gaining informed consent, it was made clear to the students that if they did not wish to take part in the study then they would not have to complete the questionnaire. Nevertheless, since the retrieval activities and exam questions planned were not beyond the scope of what would normally occur in the lesson anyway (and would be good revision), then they would still complete those but their results would not be collected or included in the research. Participants were also offered no incentives for taking part in this research.

Power Relations

Another important consideration was the power relationship which may have occurred as a result of my role as both teacher and researcher. Despite this dual role, I do not believe it created 'tensions' as the BERA (2018) guidelines suggest can happen. The reason for this is because the retrieval resources created and used were used to assess if they did have an impact on student attainment and identify the students' opinions of them. This is the sort of open and candid conversation that usually occurs between myself and my students. Participants were informed that this study sought to gain only their honest opinions and these would not offend me in any way. Equally, because the questions asked about the resources rather than my own teaching for example, I felt that participants would still answer honestly. In my opinion this lessened the power dynamic and potential student fear of answering authentically. Additionally, Lindeke *et al*., (2000) note that asking for consent directly from the participants allows the participants to feel more in control and lessens the power dynamic slightly.

Privacy and Data Storage

Participants were informed that the paper questionnaire (Appendix A) which they completed would be anonymous. Most of the questions on the questionnaire involved circling a number on a Likert scale and therefore they would not be identifiable by handwriting (Farrimond,

2000). There was an additional comments box which students could fill in if they wished, but they were informed that it was not compulsory.

The attainment data collected from students completing exam questions was the type of data that would usually be collected as normal teaching and learning practice. In line with General Data Protection Regulation, participants were made aware of how and why their data was being stored and to whom it was being made available (BERA, 2018). Participants were informed that their data would be used in the results section of the research project but that it would be anonymised. For example, each participant would be assigned a pseudonym such as 'Student A', by which they would be referred. The real name of 'Student A' would be kept secure in my personal mark book and later destroyed upon completion of the project. Participants would not be identifiable from anything written in the research project (Schenk & Williamson, 2005).

Limitations of the Methodology

There are several limitations to the methodology used in this investigation. First of all, the small sample size is not very representative of the rest of the school or UK A-Level population making it difficult to draw conclusions. Additionally, as participants completed a paper questionnaire there is the potential that I, as teacher and researcher, would recognise their handwriting and so it would not be truly anonymous. This was something that was considered prior to the investigation. However, it was decided that given that the answers to the questionnaire was not sensitive information, and that the questionnaire was asking questions that I would normally ask my students then they would still wish to answer. That said, pupils may potentially have answered in a way they felt that I would want them to, rather than honestly. The other alternative was to make this questionnaire accessible online. Doing so would then have run the risk of not everyone completing the questionnaire as it becomes more voluntary and they may forget to do it for homework. In future, the questionnaire would be online and participants would be asked to complete the questionnaire using a laptop during lesson time. This would tackle the problem of anonymity and ensure and increased response rate. It would still be important to ensure that participants did not

feel coerced and still felt free and able to opt out. Limitations with the Kahoot quiz included problems with signal or telephone devices and so not all participants were engaged.

Findings and Discussion

This section describes the findings of this investigation and how they link to each research question. Alongside this, it discusses the findings and how they relate to the literature. Each research question is addressed in turn and in separate subsections. The research questions that this study sought to investigate were:

1) How can retrieval practice be embedded into A-Level Biology lessons?
2) What is the impact of retrieval practice on attainment in A-Level Biology lessons?
3) What are student perceptions of how retrieval practice has impacted their learning?

Embedding Retrieval Practice in A-Level Biology Lessons

The first research question explored how retrieval practice could be embedded into A-Level biology lessons. Three methods of retrieval practice were used over the course of four lessons. These were: a retrieval reflection ticket, low stakes quizzing and concept mapping. This subsection describes how each retrieval practice method was implemented in the classroom, how data was collected and analysed and any limitations. Intertwined within this are comparisons to the literature.

Retrieval Reflection Ticket

The first resource used was a retrieval reflection ticket. The inspiration for this came from a book by retrieval practice enthusiast, Katie Jones (Jones, 2021). Participants were given the retrieval reflection ticket at the end of the first lesson. The retrieval reflection ticket asked participants to note down areas of strength and confident recall as well as gaps in their knowledge. The first lesson was an appropriate time to do this as participants had just completed their first attempt at the past paper questions (pre-RP) and undoubtedly, they would have some knowledge that they remembered and some that they did not. This method allowed participants to summarise what they needed to focus on going forward. It also allowed me to structure upcoming lessons to be of benefit to the participants. Jones (2021) notes in her book that identifying gaps in subject knowledge is good

for both student and teacher. A selection of responses to the retrieval reflection ticked can be found in Table 3.

Table 1

A table showing a selection of responses to the retrieval reflection ticket

Areas of strength/confident recall	**Gaps in knowledge**
Punnet squares.	*Sex-linkage questions.*
I know what things mean and how to explain answers verbally but struggle to get the mark points down.	*Knowing how to explain why something is dominant or not. I understand, I just don't know how to write it.*
Working out genetic problems.	*Definitions of what recessive and phenotype are.*
Can work out the chance of a person having the disease.	*Can we go over Hardy-Weinberg?*

The responses in Table 3 are just a small selection of the responses given. All students participated in this activity. There were thoughtful responses from each participant indicating that they were taking the self-reflection seriously. I liked this method as it gave participants the opportunity, after testing themselves with exam questions, to reflect on what they knew. This then allowed participants to determine what they needed to focus their studies on in future. This cycle of self-testing, assessing one's own knowledge and using that to inform the next phase of learning forms the basis of Nelson and Narens (1990) framework of metacognition. Although the reflection retrieval ticket was not an act of retrieval in itself, the opportunity for participants to monitor their own knowledge was important (Rhodes, 2019). Karpicke and Grimaldi (2012) mention reflection and metacognitive awareness as being indirect effects of retrieval practice. Whilst this activity may not directly affect the retention of new and future information it is still very important. I have since used this method again with a variety of different classes as allowing time for students to reflect on their learning and be metacognitively aware is useful.

Low Stakes Quizzing

As a result of the retrieval reflection ticket and participants' comments referring to defining key words in a way which will achieve marks in the exam, it was decided to try some low stakes quizzing. Within the literature there is evidence that quizzing allows information to be retained and recalled more so than restudy (Roediger & Karpicke, 2006b; Soderstrom *et al*., 2016). Quizzing can be a valuable learning tool too, especially when seen by students as a low stake learning opportunity rather than a formal assessment which may induce panic (Minear *et al*., 2018). For this, I made a Kahoot quiz for the participants to complete in class. Each question was multiple choice thus allowing the testing of basic recall and some higher order thinking (Smith and Karpicke, 2014). Appendix D shows some examples of the types of quiz questions. This method was chosen because it was low stakes and so it did not matter if participants got the answers wrong. Kahoot also randomly assigns each player a name thus making the quiz somewhat anonymous. It was hoped that anonymity would prevent participants from feeling pressure or embarrassment if they answered a question wrong. It was impossible for anyone to be identifiable from their Kahoot name unless they revealed it themselves. Kahoot can be played with a mobile telephone and no app is required making it relatively accessible to participants. That said, some participants did not have mobile data and so could not partake individually. Some joined with another person and worked together while others did not join at all. Since the questions along with the four multiple choice answers appeared on the whiteboard at the front of class all participants could take part in some form even if they had no mobile device.

Since I created the quiz, it was tailored to what the participants needed to know. I would use this quiz method again as it was a quick and engaging way to test pupils' recall. The use of MCQ has been shown to improve retention of information in participants (Smith and Karpicke, 2014). Some of the questions were answered very quickly by pupils whereas other questions took slightly longer to be answered. This indicated that participants found some questions more difficult than others. Whilst I appreciate that is my own interpretation, I do believe that some of the questions provided

the 'desirable difficulties' noted by Bjork (1999) as being beneficial to learning. However, I do not think it is the most effective retrieval practice technique. It can be perceived as slightly 'gimmicky' and as such not all participants were seriously engaged. Also, the quiz only tested a superficial amount of A-Level content. By the nature of the quiz being multiple choice, pupils were exposed to incorrect answers which could potentially negatively affect the learning of correct information (Roediger and Marsh, 2005; Butler *et al*., 2006). Additionally, since the quiz was anonymous, it was impossible to tell who was getting the answers wrong. In order to prevent incorrect answers being learned, the game was paused between questions to provide feedback on why an answer was wrong (Roediger and Marsh, 2005). Furthermore, the requirement for mobile data was an issue for some and led to less participation that anticipated. Despite the disadvantages, I do think this quizzing activity provided useful retrieval opportunities. It may be better suited in those lessons where the pupils are not fully engaged in work as a bit of light hearted retrieval. As, Agarwal *et al*., (2021) note, any retrieval is better than no retrieval.

This resource was shared with a colleague in the Biology department who also teaches this content with her A-Level class. She really enjoyed using it and thought it was a good way to test the definitions of words. She said '*it worked well at the end of our double lesson to recap some of the words we learned. As you can imagine, that group got rather competitive*'. She also said *'definitions often get overlooked during revision and the wording of them is important as the mark schemes can be fussy. They are easy marks to get in an exam if they get them right*'.

Concept Mapping

The final activity used with participants was a concept map. A concept map involves students writing down all that they know about a particular topic. The topic can often be split into different subtopics and links are made between these (Francis *et al*., 2020). In the pre-RP questionnaire responses only two participants mentioned that they themselves used a similar technique of a 'brain dump'. So, I knew concept mapping was not popular amongst the participants. Personally, I thought this would be a great way to link together all of the genetic concepts that they

had been taught and for students to really think about the topics that they knew (Carpenter, 2009). Participants were given a piece of A3 paper containing subheadings and were asked to work in pairs to freely recall any information that related to the pre-existing subheadings and then write it down on the paper (Appendix E). They had to do this purely from memory and were not allowed to use their notes or textbooks to help (Blunt and Karpicke, 2014).

Analysis of Responses

At first glance, it was noted that the amount of participant responses varied. Figure 3 shows two concept maps, from two different pairs of participants. They were chosen to highlight how dramatically different the level of responses were on this retrieval task. As can be seen in Figure 3, some concept maps contained lots of participant responses whereas on others, entire subheadings were left without any written participant response. For those maps which were returned with very few responses, I feel that this is because participants perhaps did not engage in the task very well or see much value in it. Though it could also be that they did not know the content. But given how their scores improved on the post-RP past paper questions (discussed further on), I do not think that this was the case. Additionally, Carpenter (2009) suggests that concept mapping may actually be more useful to those with less prior knowledge. Therefore, I would have assumed that most participants would be able to access this retrieval practice technique.

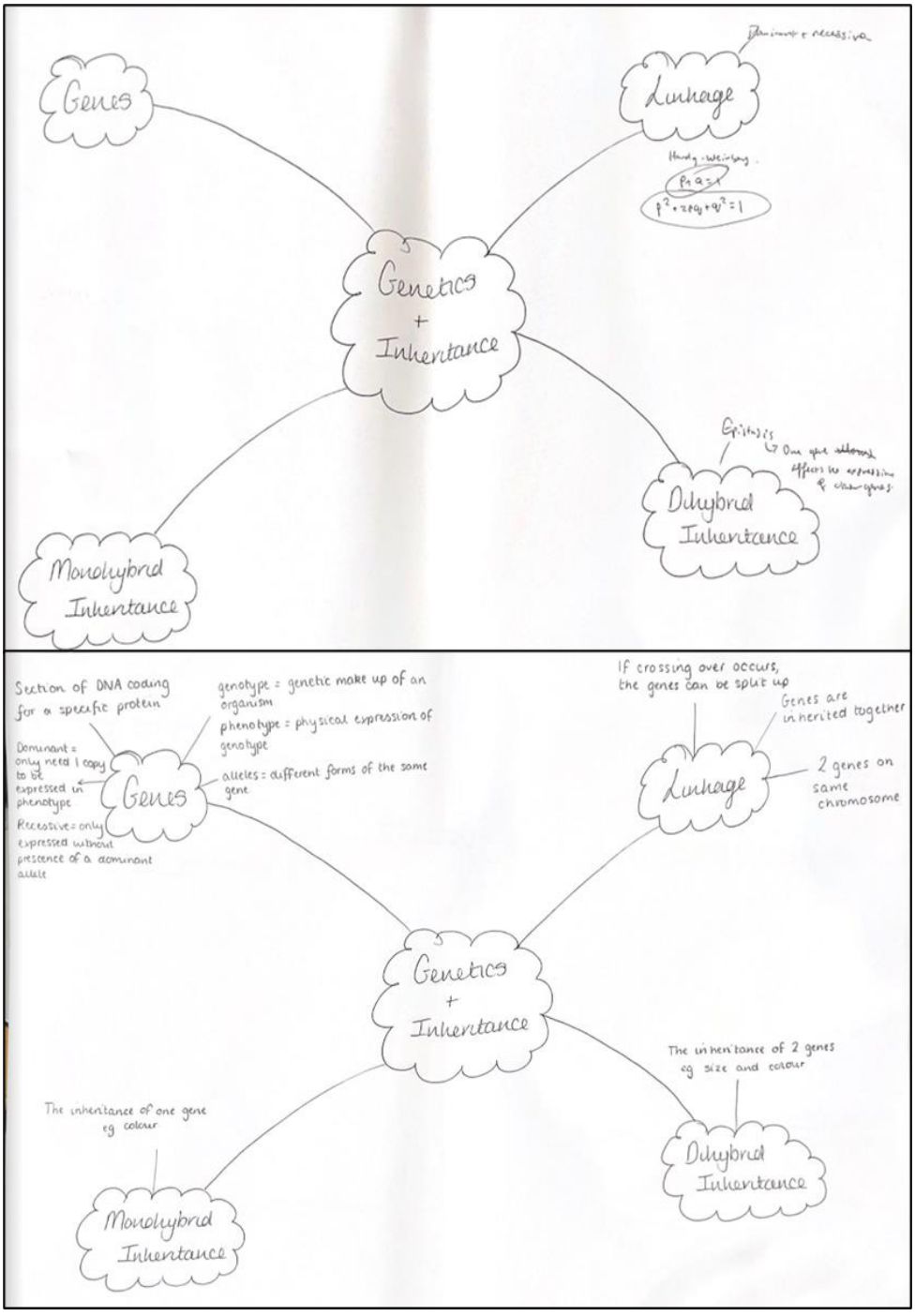


Figure 3: Examples of two concept maps which were analysed.

The concept maps were analysed by thematic analysis. In thematic analysis, patterns in data are identified and are usually fairly flexible in nature as long as they present something interesting about the data in relation to the research question (Braun and Clarke, 2006). The participants' responses were initially examined to identify key features that stood out, as well as noting any similarities or differences between responses. Given that this was a knowledge-based task, rather than participants' opinions for example, the responses to this concept map were very much factual and recall based rather than opinion. Therefore, it was quite challenging to devise themes or particular patterns in responses. After much thought, participants' responses were categorised into the following themes: subheadings with short answers, definitions, diagrams or explanations of concepts. This revealed how retrieval was utilised.

There were a few concept maps where there were only short answer responses (Figure 4). Here the participants have stated some different types of genetic linkage for example: '*autosomal linkage'*, '*sex linkage'* and '*on the same chromosome'*. Participants have engaged in retrieval by remembering that there are two different types of linkage but have not expanded further on this. In contrast, the same subsection was answered by another pair of participants and responses can be seen in Figure 5. Here, the participants offered some explanation of what the different types of linkage were. For example: '*sex linkage is where the allele is on the X chromosome'*. It is impossible to know from this data whether the responses seen in Figure 4 were limited because participants did not remember any more information that what they wrote down. Or whether it was because they did not feel prompted by the task to expand upon their answers.

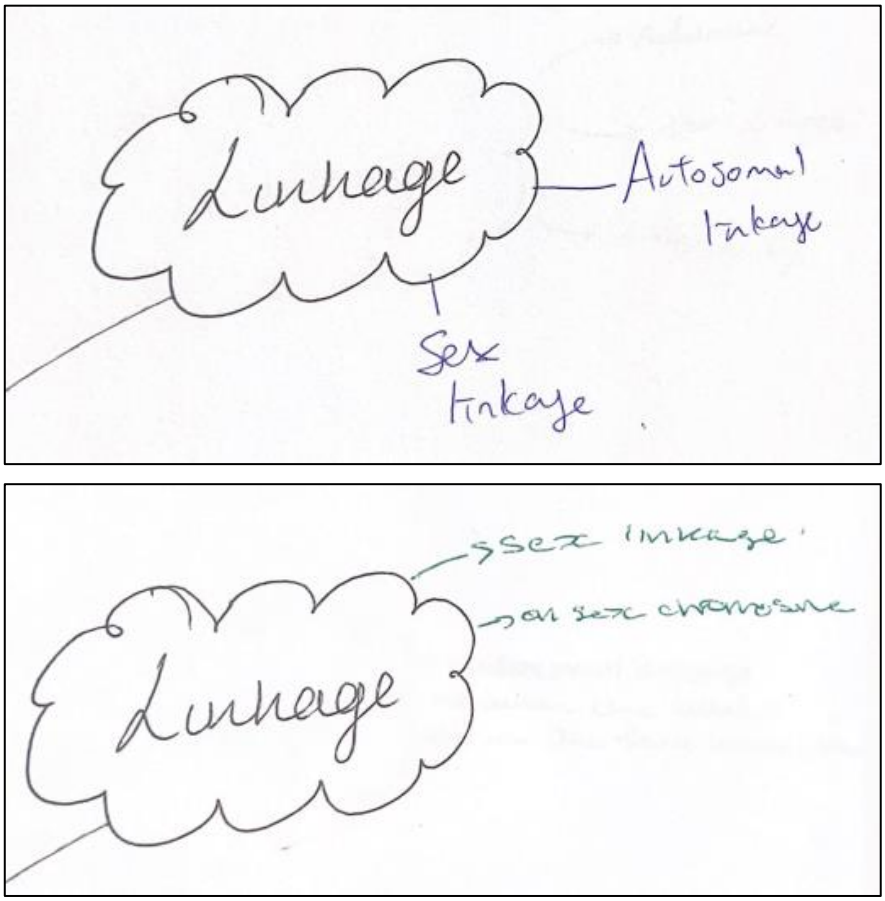


Figure 4. Examples of responses where participants have used short answers.

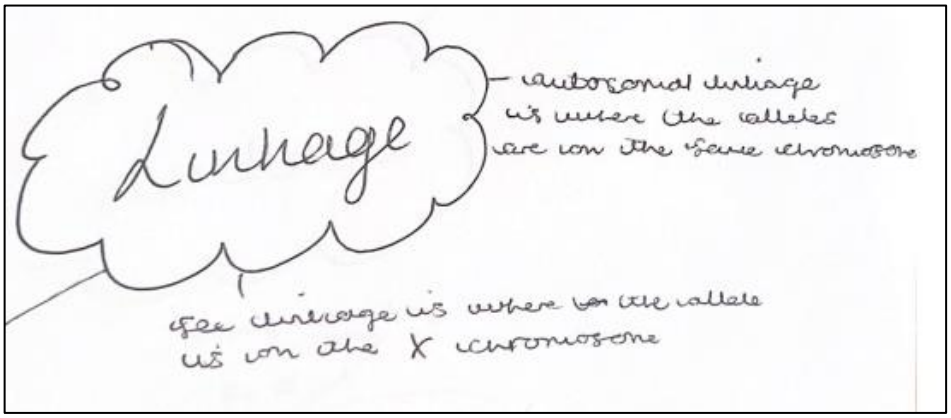


Figure 5. An example of a response where participants have given explanations.

By far the most common type of response to the concept maps was to include definitions. This can be seen in Figure 6. Across all of the concept maps, all of the definitions that were written down were defined correctly. Perhaps this was due to the practice participants had when they

participated in the Kahoot quiz. However, once again it is difficult to know this for sure. There were also a few instances of participants using diagrams to display their knowledge. This can be seen in Figure 7. Here, the participants show how the chromosomes can contain two different genes which are inherited together indicating that they know how dihybrid inheritance works. That said, apart from this diagram there was very little else included in their concept map and there was no more information written down in words.

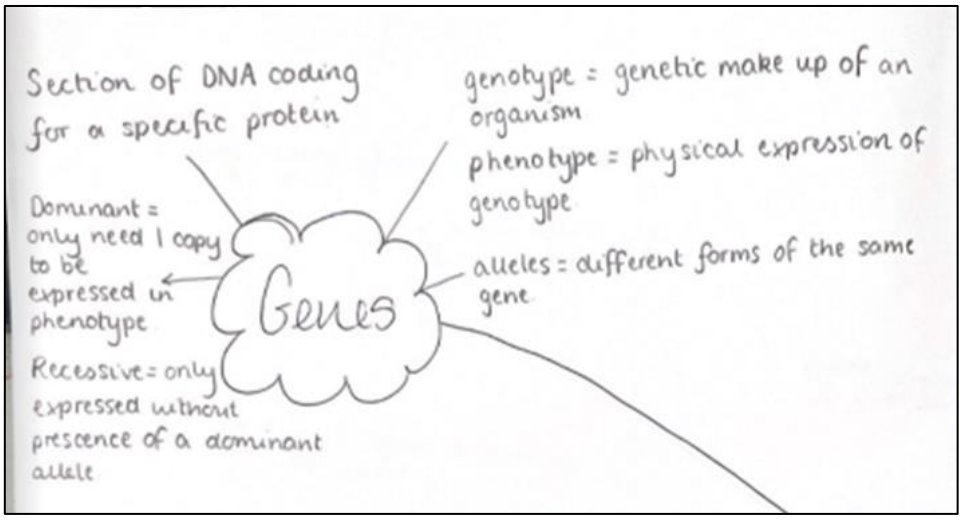


Figure 6. An example of how some participants responded using definitions.

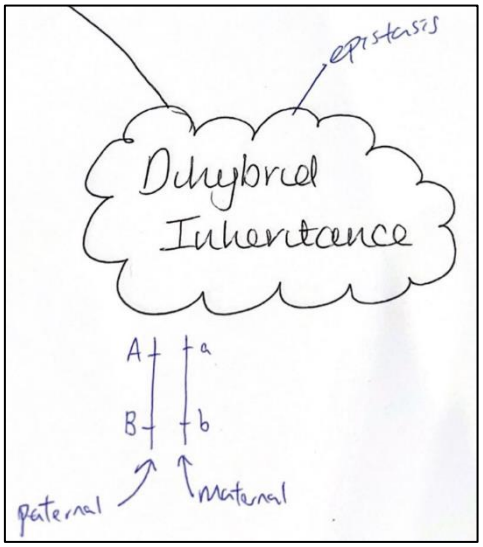


Figure 7. An example of how some participants responded using diagrams.

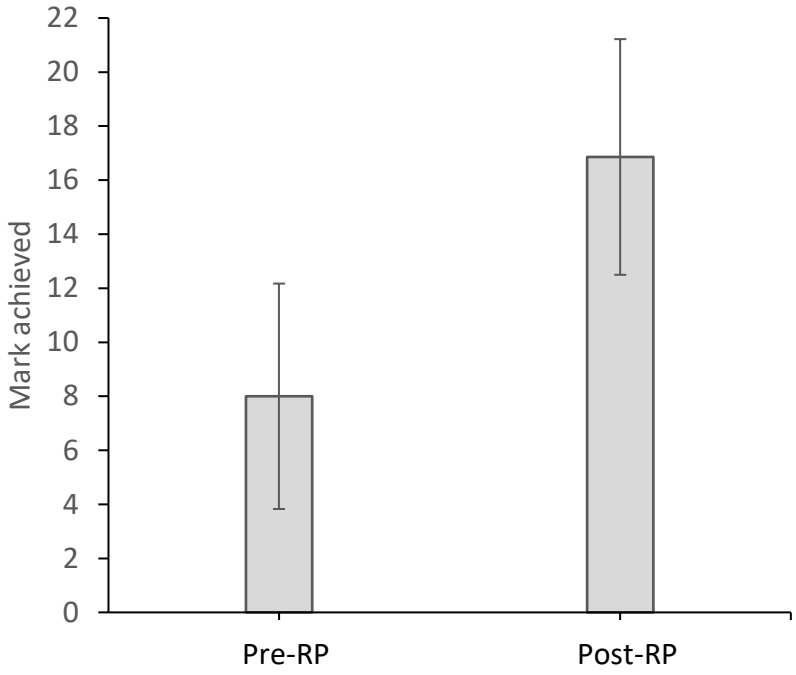
Reflections on the Implementation of Concept Mapping

This task was completed to varying degrees by all of the participants. Some seemed to embrace the retrieval and others seemed to write very little. It is unclear whether this is due to a lack of knowledge or engagement. That said, at least every pair wrote something down even if it was not very much. At this point, it is important to justify why the concept mapping was conducted this way. Firstly, concept mapping was chosen as it is low stakes. As stated earlier, retrieval practice should be a learning tool not an assessment tool (Jones, 2019). Secondly, concept mapping allows students to visually organise their knowledge and link it to other facts (Francis *et al*., 2020). The reason that I chose to give participants an A3 piece of paper with subheadings already written on it was because this was not a technique that I had used with these participants before. It was hoped that this would provide a starting point for the participants so that everyone could respond.

With hindsight, providing subheadings was unhelpful and had the unintended, opposite effect of limiting the scope of what participants felt they could write. Equally, upon reflection, I feel that the genetics topic does not lend itself to this kind of retrieval activity. A lot of the exam questions relating to this topic are problem solving questions which calls upon problem solving skills more than information recall. Perhaps concept mapping would have worked better with another topic that is covered in A-Level Biology such as proteins. Proteins is a topic with much greater and more obvious links to other A-level Biology topics. Additionally, rather than having one-word subheadings as I did, a broader focus question to start students may have been more useful in stimulating participants' thoughts. A question such as 'what is the importance of proteins?' would have provided participants with the opportunity to recall and explore lots of biological links without the activity being as prescriptive as it unintentionally was. Although I do not think that I embedded this technique into my lesson very effectively, I would try it again with the suggested adjustments as I do believe that this could be a valuable retrieval technique.

The Impact of Retrieval Practice on Attainment

Within this subsection, the findings pertaining to research question two (RQ2) will be addressed. It will first remind the reader of how data was collected and then explain how it was analysed. Finally, it discusses any potential impact retrieval practice has had on attainment as well as potential limitations in the method and analysis. To answer RQ2 participants completed past paper exam questions in lesson one (pre-RP) and then again in lesson four after retrieval practice had taken place (post-RP). In total, 21 participants took part and completed both the pre-RP and post-RP exam questions. As mentioned previously, the exam questions were chosen by myself and as far as I was aware the students had not completed these questions before this investigation. The questions were also marked by myself using the exam board mark scheme. There were a total of 22 marks available. The average results from pre-RP and post-RP are shown in Figure 8. The average participant score on the pre-RP exam questions was eight out of a possible 22 marks. In lesson four, the post-RP average score was 16.9. This showed quite a dramatic increase in the average score. The standard deviation was calculated for the data before and after. From the graph in Figure 8, it can be seen that the standard deviation bars to not overlap for the pre-RP and post-RP data indicating a significant difference between the scores achieved pre-RP and post-RP.



Note: Error bars show standard deviation

Figure 8. A graphic showing the participants' scores on past paper question before and after retrieval practice.

Figure 8 shows that the average attainment on the past paper questions increased by nearly nine marks (8.9) after retrieval practice took place. Appendix H shows the breakdown of each participants score pre-RP and post-RP. Every participant's score increased. The smallest increase was by one mark with the largest increase in score being 19 marks. Although results indicate that retrieval practice has caused the score to increase significantly, I am wary about drawing such conclusions. This is because, although retrieval practice may have played a part in increasing overall attainment, the design of the experiment does not allow me to work out the extent to which this increase was down the retrieval practice or other factors. Whilst Roediger and Karpicke (2006b) note that retrieval practice is better than restudy for retention of information, restudy does still increase retention. And in this investigation, both restudy and retrieval took place. Equally, participants were aware that they would be facing the same exam questions again so there was nothing to prevent

them from completing additional revision outside of the classroom which could have contributed to their increased scores.

This uncertainty is a relatively large limitation of my investigation. Perhaps rather than restudying the topic with participants in class, I should have done even more retrieval practice with them. Then through feedback of responses, I could have addressed gaps in knowledge or misconceptions with students. Additionally, if the investigation had taken place over fewer lessons this would have given participants less opportunity to conduct their own private revision which may have ultimately contributed to their improved attainment. Furthermore, I could have not informed participants that they would be completing the same exam questions again. They would then have been unaware that they would be assessed again thus reducing the motivation for their own private study. However, I wanted to be open with participants about what the investigation entailed. Plus, knowing my students, they would have panicked if I had sprung some questions on them which they were not expecting.

Student Perceptions of Retrieval Practice

In order to address RQ3 regarding student perceptions of retrieval practice, participants completed a questionnaire at the start of this investigation (pre-RP) and again at the end (post-RP). The questionnaire was adapted from Cervin-Ellqvist *et al*., (2020). It sought to uncover the strategies used by students when they study along with their justifications. This subsection will discuss each questionnaire item in turn and compare pre-RP and post-RP findings for each question.

Number of Study Strategies Used by Students

The first question asked participants to list all of the study strategies that they use when preparing for a biology exam. Participants then also had to rank those strategies in order of most to least used. To analyse the data, the written responses were manually entered into an excel spreadsheet along with the number used to rank that strategy. If a participant ranked two or more strategies as equally used the most, then those strategies were all listed and given a rank of one. This was in line with how Cervin-Ellqvist *et al*., (2020) dealt with a similar situation. Figure 9 shows

that the maximum number of different strategies listed by students pre-RP was four. The most common number of strategies listed was three with the average number of strategies listed being 3.3 (M=3.3). Karpicke *et al*., (2009) asked a similar question in their research and their undergraduate participants listed three strategies on average, with six strategies being the maximum listed. Participants in the research by Cervin-Ellqvist *et al*., (2020) also listed three strategies on average. The results from the post-RP questionnaire were analysed in the same way. Figure 10 shows that the maximum number of different strategies listed by students was again four. However, the frequency distribution was slightly different to the pre-RP results. In the post-RP results one person listed only one strategy whereas no one did this in the pre-RP questionnaire. The most common number of strategies listed was still three but the average number was 2.85 (M=2.85) which is a very small change from pre-RP results.

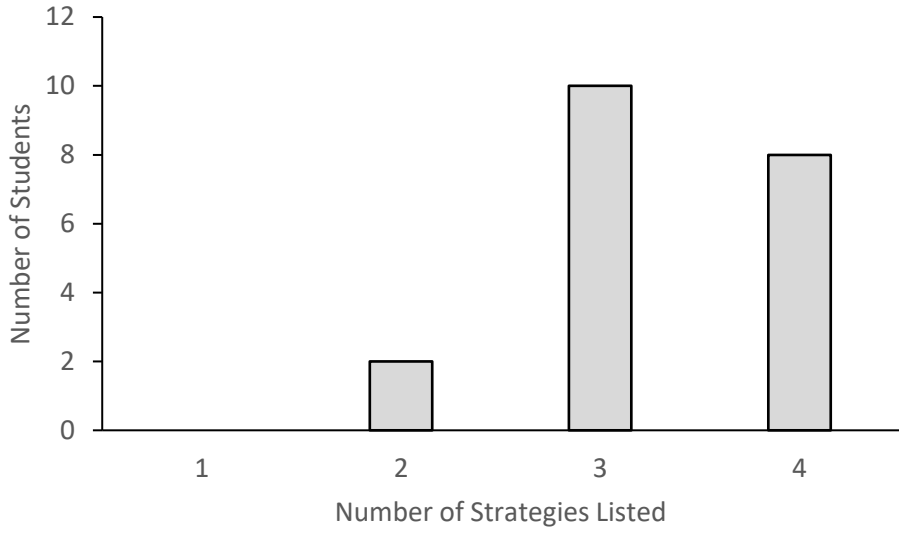


Figure 9. A bar chart showing the frequency distribution of the number of strategies listed by participants pre-RP.

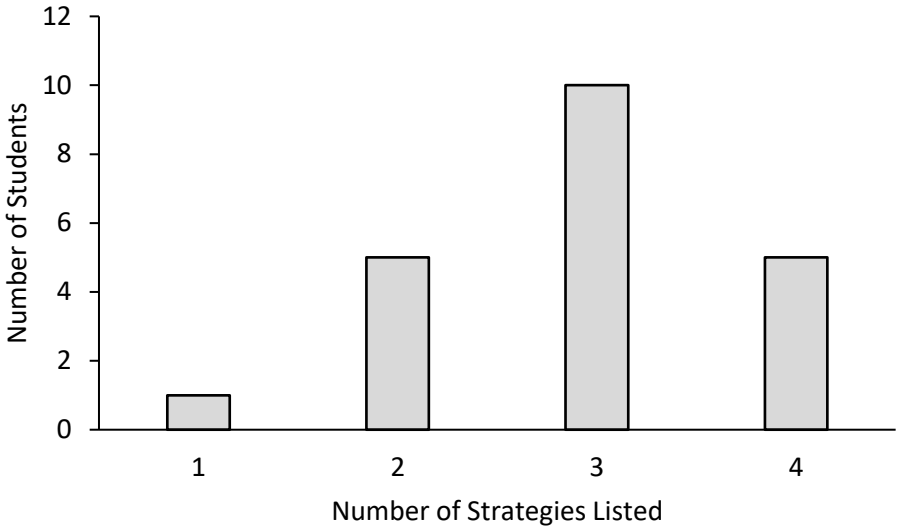


Figure 10. A bar chart showing the frequency distribution of the number of strategies listed by participants post-RP.

From Figure 9 and 10, the comparison between pre-RP and post-RP results does not seem too dissimilar. The one main change, is that post-RP, one participant has listed using only one study strategy. As a teacher, I would not advise a student to only use one particular method and to be honest, I cannot fully believe that this is genuine. Perhaps this is true, and post-RP this individual has settled on one study strategy only. Or, perhaps they were slightly disengaged with the questionnaire a second time around and did not answer honestly. There is no way to tell, but it is definitely something that crossed my mind. Despite my suspicions the result has been included.

Types of Study Strategies Used by Students

The pre-RP responses to the questionnaire highlighted that there were 11 different strategies mentioned by all of the participants. Of these, six strategies were mentioned by more than one person. These six strategies, along with the number of participants who listed them and how many participants ranked it as a number one strategy, can be found in Table 4. Using past papers ranked as the most popular strategy, with 19 out of the 21 participants listing it in their response. However, only three of these students ranked it as their most used strategy. This indicates that although it was a significant strategy in the majority of the participants revision strategies, it

was most likely not their first technique. This compares to 83.2% of the participants in Cervin-Ellqvist *et al*., (2020) research who listed studying old exams as a frequently used strategy with 38.5% of those participants ranking it as their number one strategy. In the post-RP results, 20 out of 21 participants listed using past papers as a study strategy (Table 5). Six participants also ranked this as a number 1 strategy which, at first glance, is slightly higher than the pre-RP results. Although no statistical test was performed to see if they were statistically different. Additionally, in the post-RP results, participants listed 13 different strategies rather than 11. The extra two included 'retrieval practice' and 'using quizzes'. It is hoped that these responses were genuine and not participants mentioning them because they felt that these were the responses that I wanted to see written, given the nature of the investigation. Again, this is another potential limitation of being both teacher and researcher.

Table 4

The six most used strategies pre-RP and the frequency of participants who ranked it number one.

Strategy	Number of participants who list strategy	Number of participants who rank as a number one strategy
Past papers	19	3
Flashcards	17	8
Make notes	14	7
Read notes	9	5
Talk with others	4	1
Blurting	2	1

Table 5

The six most used strategies post-RP and the frequency of participants who ranked it number one

Strategy	Number of participants who list strategy	Number of participants who rank as a number one strategy
Past papers	20	6
Flashcards	16	7
Make notes	10	7
Read notes	7	2
Quizzing	3	0
Talk with others	2	0

The second most popular strategy pre-RP was the use of flashcards with 17 participants mentioning it in their responses (Table 4). Eight participants ranked this method as their number one strategy. Therefore, flashcards had the greatest number of participants ranking it as their number one strategy. Post-RP results were similar in that 16 students listed it as a strategy with 7 students ranking flashcards as their number one strategy (Table 5). Nevertheless, at this point in the questionnaire there is some ambiguity as to how the flashcards were used by participants. Some participants offered some insight stating that they use flashcards to '*summarise their notes'*, to '*write down specific mark points'* they needed to learn or to '*write questions'* which could be used to self-test. But there were others who did not expand any further than simply writing '*flashcards*'. This was a significant limitation of the free-response nature of this question. It made it impossible to categorise whether participants were using retrieval practice with these strategies or not. For example, do these participants use the flashcards to practice recalling the information on the cards? Or do they simply re-read the notes on the flashcards? Karpicke *et al*., (2009) also found this issue with the questionnaire in their research. They too found that a lot of their participants used flashcards or answered practice questions. But the majority of participants did not expand on how either were used. Karpicke *et al*., (2009) quite rightly suggest that some participants could be

answering the practice questions by looking up the answers and so not actually engaging in retrieval. They too also echo my concerns about how students may be using flashcards in a way that does not involve retrieval practice. As such it is difficult to make any major judgment on how much retrieval the participants of my investigation engage in.

Making notes and reading notes were mentioned in the pre-RP investigation 14 and nine times respectively (Table 4). This decreased to 10 and seven respectively in the post-RP questionnaire (Table 5). However, as previously stated, this could have also been a technique used in conjunction with the flashcards so may actually occur more frequently than the data in Table 4 and Table 5 suggest. Making and reading notes were ranked as a number one strategy by 12 participants in the pre-RP questionnaire. This is more students than those who ranked past papers and flashcards as a number one strategy combined. This changed post-RP and there were a greater number of participants ranking past papers and flashcards as a number one strategy. These results indicate that pre-RP, students in my classroom were utilising techniques that do not require recall and have been shown in educational research not to be effective (Dunlosky *et al*., 2013). Karpicke *et al*., (2009) also raised concerns with their findings. They found that 84% of participants engaged in reading notes with 55% ranking it as their number one strategy. This made it the most favoured strategy in their study.

Karpicke *et al*., (2009) also found that only 11% of their participants engaged in retrieval practice. 'Blurting' was a strategy that was mentioned by two students in the pre-RP findings but only one of the students ranked it as their number one strategy. From their explanation of the process, it was deemed by myself to be an act of retrieval. 'Blurting' involves writing down everything that is remembered about a particular topic and it acts as a way to retrieve information, similar to concept mapping. Blurting did not appear as a most used strategy post-RP. Instead, it was replaced by quizzing. Of the participants who mentioned the use of quizzing, there was no expansion of this response. Participants did not mention how they use the quizzing. For example, whether it was online or individual. This once again is a limitation of the questionnaire. Although it is really

encouraging that students are mentioning quizzing, which is a retrieval activity, I hope that this is a strategy which is genuinely used and not just mentioned because they feel it is what I want them to write.

Student Justifications for Using Certain Study Strategies

The second question in the questionnaire asked participants to explain why they used the strategies that they use. The following paragraphs will relay the justifications offered by participants for using the top six strategies pre-RP (Table 4). Since the questionnaire was anonymous, it is impossible to know which comments relate to which participant. Therefore, responses from the questionnaire will be quoted and then discussed. There were several participants who wrote comments such as '*see what exams might be like*', '*exam questions let me see how the exam will be set out*' and '*get used to the questions*'. These comments were in relation to the use of past paper questions. There were similar justifications to this in the Cervin-Ellqvist *et al*., (2020) research. In their study, the authors categorise these justifications as a '*metacognitive strategy*'. In both cases, participants were using the past papers in an undoubtably useful way. But their motivation was to assess what they may be asked in an exam in order to influence what content they learned. They were not using the papers directly for retrieval purposes. Several students did mention that the use of past papers allowed them to '*practice application questions*' and to '*check I know everything and practice revision*'. One participant mentioned that they complete the questions and then '*self-mark with the mark scheme*'. Previously, I expressed concern that participants may be using their notes to answer the questions rather than using retrieval. At least for this participant that is not the case. From these responses it suggests that some participants are using a self-testing approach and are using retrieval practice (even if they do not directly call it that). As Cervin-Ellqvist *et al*., (2020) state, using past papers helps students to evaluate and monitor their understanding. However, no one justified their answers by saying that the act of testing themselves strengthens memory of that information and benefits the learning of new information (Soderstrom *et al.,* 2016).

Flashcards, the second most popular strategy, were also used in a variety of ways and for a variety of reasons. Most participants mentioned that they were '*helpful for keywords*' or useful for writing out a '*model answer*'. Some students even expressed how they used the flash cards, for example '*make flashcards of things I got wrong so that I can learn them*' or '*asking myself a question and memorising the correct answer*'. Two participants also mentioned '*testing knowledge needed for the exam*' and one other student went into more detail by saying that they '*write mark points on flashcards - learn, cover, recite until I know them off by heart*'. This allowed a greater insight into how the participants used this technique. Again, the testing is useful and shows that participants are metacognitively aware and are actively testing themselves to assess what they know. This is an indirect effect of retrieval practice (Karpicke *et al*., 2009). For those participants who mentioned writing out answers, it was less clear what they do with those strategies. Do they use them to re-read or are they too testing themselves on the mark points and key language needed to score marks in the external exams? Cervin-Ellqvist *et al*., (2020) also had participants use flashcards in a similar way. But they had some participants who reported using this method as it was a '*fun way of studying*'. This justification links less to cognitive benefits and more to student motivation in studying.

Making and reading notes were two other very popular strategies amongst the participants in my study. A few participants mentioned '*condensing notes*' with one student saying '*making summary notes helps me make sure I have an understanding of each topic and I write it in a way I will remember*. *It also lets me know what I don't understand/need to focus on'*. This strategy is being used in a metacognitive way. One participant said that they '*memorise at the same time as I write*'. In my opinion I am not sure how much this participant can defend the idea that they can memorise something as they copy from previous notes. There is no active recall testing whether the memory has been made. For those that read over notes, the justifications included '*used if I don't understand a topic*' and used to '*rejog my memory and fill in knowledge gaps*'. Again, this is a metacognitive use and one which I can appreciate may be useful in the early stages of preparing for an exam. Another

student noted that they '*re-read notes at further intervals*'. Whilst another participant said that they '*test myself by covering up my notes*'. In this sense they are testing whether they can recall the information. But the participants are not demonstrating an understanding that practising retrieval can benefit future learning (Pastötter *et al.,* 2011).

The final two strategies in the pre-RP top six were: talking with others and blurting. The participants who mentioned talking through content with others justified this by writing '*explaining processes to my sister gives a deeper understanding*' and '*testing myself with others tells me what I do and don't know so I can focus my revision further*'. 'Blurting' was the final strategy to appear in the top six. The two participants who mentioned it justified their use in the following ways '*rewrite as much as I can from memory helpful for memory/retrieval*' and '*I write subtitles and write everything I know and then I use my notes to fill in what I don't know*'. Both of these methods involve actively recalling information which in turn strengthens memory and the ability to recall again in the future (Soderstrom *et al.,* 2016).

Having discussed the pre-RP results of question two in some detail, the following paragraphs will briefly mention some highlights from the post-RP responses to question two. Table 5 shows that in the post-RP questionnaire past papers and flashcards were ranked as the two most popular strategies. This is the same as in the pre-RP questionnaire. It shows that participants feel confident in these techniques and believe that past papers and flashcards are an important part of revision. Justifications for the use of past papers remained largely unchanged compared to pre-RP. Again, the most common reasonings were to '*check I know it*' and '*see what sort of questions they might ask*'. It appears this strategy is still being used metacognitively (Cervin-Ellqvist *et al*., 2020). Flashcards also remained popular post-RP and again justifications and explanations for the way in which they were used remained largely unchanged. One response did say that they '*help me remember'* but there was no further expansion on this fairly vague response.

Re-reading and note taking were still top six strategies post-RP. This did surprise me slightly since, in the course of my teaching, participants were told how both of these were quite passive

processes. It does however appear to be a popular strategy amongst other students too. With Dunlosky *et al*., (2013) finding that 84% of participants in their study re-read information as a study strategy. Perhaps it is a 'comfort blanket' for students as the more they read the information the more 'fluent' they become in reading it (Karpicke *et al*.,2009). Students then mistake this feeling of fluency for understanding and retention (Tai *et al*., 2018). Quizzing made an appearance in the top six strategies. An example of a reason given for this included '*see if I can remember under pressure'*. Whilst quizzing is an example of retrieval practice, and this response does touch on the idea of testing memory, it does not demonstrate that the participant is aware of the direct and indirect effects of retrieval practice (Karpicke *et al*., 2012).

Student Perceptions of Study Strategies

The final item of the questionnaire asked participants to read through the study strategies that were listed and to do two things. Firstly, participants were asked to indicate which strategies they use from a given list. Then for the strategies that they use, participants were asked to pick a number between one and three based upon how helpful they found the strategy. One was rated 'not helpful' and three was rated 'very helpful'. The pre-RP and post-RP results can be seen in Table 6 and Table 7 respectively. This subsection will discuss the results of this final questionnaire item and compare the 'helpful' rating to utility ratings given by Dunlosky *et al*., (2013). Before doing so, it is important to briefly describe the paper by Dunlosky *et al*., (2013). These authors reviewed the literature on popular study strategies and examined each strategy across four categories. These categories included: learning conditions (i.e. group work or individual), student characteristics (i.e. age, ability and prior knowledge), materials (i.e. simple recall or difficult problems) and criterion tasks (i.e. whether students were assessed on attainment, comprehension or problem solving). This culminated in each strategy being giving a utility rating which has also been included in Table 6 and Table 7. For the purpose of this investigation, the terms utility and helpful are equivalent.

Table 6

A table showing how helpful participants perceive different study strategies to be pre-RP and how that compares to Dunlosky *et al*., (2013).

Strategy	Frequency of participant opinion: Not helpful 1	2	Very helpful 3	Rating of utility (Dunlosky *et al*., 2013)
Identify/come up with keywords and create mental images of those to remember/learn the information linked to keywords.	3	3	5	Low
Write summaries.	0	2	13	Low
Check what you know of the course content by testing yourself on it.	0	3	17	High
Read course material and/or your own notes more than once.	4	6	10	Low
Highlight or underline in books or notes.	5	9	4	Low
Try to explain to oneself why facts or concepts are true/correct.	1	6	4	Moderate
Try to explain to oneself how new information is related to old, or explain the different steps taken when solving a problem/ a task.	2	8	4	Moderate

Table 7

A table showing how helpful participants perceive different study strategies to be post-RP and how that compares to Dunlosky *et al*., (2013).

	Frequency of participant opinion			Rating of utility (Dunlosky *et al*., 2013)
	Not helpful		Very helpful	
Strategy	1	2	3	
Identify/come up with keywords and create mental images of those to remember/learn the information linked to keywords.	4	3	2	Low
Write summaries.	2	4	9	Low
Check what you know of the course content by testing yourself on it.	0	2	19	High
Read course material and/or your own notes more than once.	4	5	10	Low
Highlight or underline in books or notes.	4	12	3	Low
Try to explain to oneself why facts or concepts are true/correct.	1	5	5	Moderate
Try to explain to oneself how new information is related to old, or explain the different steps taken when solving a problem/ a task.	2	10	5	Moderate

The pre-RP strategy that most participants ranked as being the most helpful was '*check what you know of the course content by testing yourself on it'.* There were 20 students who indicated using this, with 17 of those ranking it 'very helpful' (Table 6). This is in line with results from Table 4 which indicates that past papers are the most used strategy by participants. Again, the wording of this questionnaire implies that the testing is purely for metacognitive purposes rather than the other learning benefits that testing has (Cervin-Ellqvist *et al*., 2020). Dunlosky *et al*., (2013) found that practice testing was of high utility across a range of ages and retention intervals. Although it is not always seen as desirable by students who quite often have negative connotations of testing (Minear *et al*., 2018). The post-RP opinions of testing are not noticeably different (Table 7). Additionally, pre-RP, 13 participants found writing summaries 'very helpful' and of the 15 participants who indicated they used this, no one indicated that they found it 'not helpful' (Table 6). In contrast, writing summaries, was deemed low utility by the Dunlosky *et al*., (2013) review. After examining the

literature, the authors concluded that this strategy was only useful for those who were good at summarising. The authors did recognise that being effective at summarising required a lot of prior training. Nevertheless, Dunlosky *et al*., (2013) did acknowledge that this conclusion was based upon a lack of literature examining how summaries help comprehension and retention of knowledge. The post-RP student opinions still indicate that a similar number of participants are still using summaries compared to pre-RP. But the distribution of how helpful these participants found summaries changed slightly, with two participants subsequently rating it as unhelpful.

Furthermore, pre-RP, 20 of the 21 participants indicated that they '*read course material and/or your own notes more than once*' (Table 6). This is not surprising given the results in Table 4. What was fairly surprising was that four of those 20 participants use this technique but rate it as 'not helpful'. Although 10 participants found re-reading notes 'helpful', the other 10 participants who indicated using it mentioned that they either found it 'not helpful' or in between 'helpful' and 'not helpful'. These results show that there were mixed feelings amongst the participants as to how helpful re-reading course material was. Dunlosky *et al*., (2013) rate this study strategy as low utility. Yet, the authors admit that this rating was based upon there being a lack of literature on the impact of re-reading on the comprehension of knowledge and on students below university age. They also suggest that the benefits of re-reading can be impacted by ability and a student's prior knowledge. Once again, the post-RP findings were very similar to the pre-RP findings. This suggests that it is a usual part of the study process, even for those participants who acknowledge its low utility. Perhaps those participants use re-reading as a metacognitive strategy to ensure that they are covering everything that they need to know. Equally, for those who still believe that it is a helpful technique, perhaps they are falling victim to the metacognitive illusion that re-reading can cause (Bjork *et al*., 2013).

The participants responses to '*highlight or underline in books or notes*' were also very mixed. There were 18 participants who indicated that they used this technique. Five of those 18 rated highlighting as 'not helpful', four valued it as 'helpful' and nine felt that it was somewhere in

between. Dunlosky *et al.*, (2013) state that based on the evidence within the literature, highlighting or underlining is not a helpful study technique and has no benefit over simply just re-reading notes. Post-RP results are again very similar to pre-RP results. However, a few more participants became of the opinion that highlighting notes is neither 'very helpful' or 'not helpful'. This is despite participants still using the strategy. Perhaps these participants simply highlight notes to help them summarise later or because it is something that they have always done. It would have been insightful to ask participants why they answered this way. This would have been possible if an interview had been included in the methodology. Overall, there was very little change in perceptions of study strategies pre-RP and post-RP. This shows that the opinions of participants are already very engrained, at least in my A-Level biology students. Perhaps more time has to be spent explaining to students what is useful when studying and what is not deemed useful.

Conclusion and Implications

There is one main underlying reason as to why this research project focused on retrieval practice. Essentially, I was becoming frustrated that the pupils that I teach were struggling to retain knowledge and I wished to improve the situation. Retrieval practice is the act of recalling previously learned information with little or no support (Jones, 2019). Retrieval practice shifts the focus away from how to get information into pupils' minds and instead looks at how to help students recall the information, thus strengthening the memory (Atkinson and Shiffrin, 1968). Many authors within the literature also note how it can improve the retention of new and future information (Roediger and Karpicke, 2006a; Soderstrom *et al.*, 2016). Much of teaching focuses on imparting knowledge on pupils (Karpicke, 2012). Whilst no one can deny that teaching and scaffolding knowledge is important, it is irrelevant if the students cannot then recall what has been taught. Even Karpicke and Grimaldi (2012) note that the frustrations that I felt may be due, in part, to a problem with the pupils remembering. Ebbinghaus' forgetting curve is a startling reminder that after 20 minutes of learning new material, only 58% of that information is retained (Ebbinghaus, 1885 as cited in Murre and Dros p.10, 2015). Therefore, the prospect of a technique which could improve the learning and retention of knowledge in my students was exciting. Therefore, this investigation set out to answer the following research questions:

1. How can retrieval practice be embedded into A-Level Biology lessons?
2. What is the impact of retrieval practice on attainment in A-Level Biology lessons?
3. What are student perceptions of how retrieval practice has impacted their learning?

In relation to RQ1, the findings indicate that in general, the participants of this study were receptive to retrieval practice. In the three retrieval tasks (retrieval reflection ticket, low stakes quizzing and concept mapping), there was pupil participation and engagement. However, the level of engagement varied between the three retrieval activities. For example, there were lots of written responses to the retrieval reflection ticket but the detail and number of responses to the concept maps were much more varied. Additionally, this study illustrated that different types of retrieval

activity are suited to different topics and different points in learning. For instance, the low stakes quiz on Kahoot was good at testing recall of definitions. But did not necessarily allow the students to form connections between knowledge to help retain information in the way that the concept map did (Carpenter, 2009; Francis *et al*., 2020). Equally, a concept map used to link information is only useful when students have studied sufficient topics to be able to make connections. Therefore, I have learned that, with careful consideration of the type of activity and the point in student learning, retrieval practice can be embedded into lessons in a variety of formats fairly easily. And its use is supported by the literature (Roediger and Karpicke, 2006a; Agarwal *et al*., 2021).

To address RQ2, participants completed past exam questions before and after retrieval practice had occurred. Results showed that attainment improved post-RP. Although, it must be remembered that this was a very small sample size and as such more rigorous statistical tests could not be applied. Furthermore, there could have been other factors which caused an overall increase in attainment such as participants doing additional study outside of the classroom. To better understand the impact of retrieval practice on attainment more repeats of this investigation would have to be conducted on a larger sample size and additional study prevented. Nevertheless, these results seem promising and match findings from the literature that show retention of information is improved with retrieval (Roediger and Karpicke, 2006b).

RQ3 explored how students felt retrieval practice impacted their learning. Students use lots of different study strategies, some of which are deemed low utility by Dunlosky *et al*., (2013). For example, in contrast to the literature, a large proportion of students deemed writing summaries as being very useful (Dunlosky *et al*., 2013). Furthermore, results remained largely unchanged between the pre-RP and post-RP questionnaire indicating that these student opinions are fairly consistent and not easily changeable. Granted these findings are from a small subset of my own school population so may be different in other settings. Moreover, it appears that students are using retrieval practice when they study although they are not necessarily aware of it. For instance, the most popular techniques listed by participants were the use of flashcards and past paper questions. Whilst some

did not go into detail on how they used these strategies, other students indicated that they used them to self-test. This is an act of retrieval whether they were aware or not. In this case, the flashcards were being used in a metacognitive manner to test what was already known and ensure the information could be recalled (Karpicke *et al*., 2009). No participants within this investigation mentioned that retrieval benefits the learning of new material too (Pastötter *et al.,* 2011). Therefore, it seems that students are unaware of how retrieval practice can impact their learning.

Implications

As a result of findings in the literature and from this study, there are several implications for my own teaching practice and the wider school environment. These implications will be discussed in this subsection.

My Professional Practice

This study has allowed me to explore educational literature and understand how retrieval practice can improve student outcomes, both directly and indirectly (Karpicke and Grimaldi, 2012). It has also shown that students are currently unaware of these benefits and are using study strategies which are not deemed very useful (Dunlosky *et al*., 2013). Therefore, going forward, I aim to teach my students about how they learn and form memories. I will also discuss Ebbinghaus' forgetting curve and explain how it can be overcome using retrieval practice (Kang *et al*., 2014). If students are made aware of the theory of memory formation, then they can practice study habits which will be of benefit to them. Appendix I shows a slide explaining retrieval practice and memory formation. It was used with a Year 9 class before they sat their end of year exams. I was amazed at how interested the Year 9s seemed when I was explaining how memories form and how to revise effectively. They were shocked at how quickly forgetting occurs. I do believe that giving them this knowledge allows them to be better learners. In addition, I aim to include more retrieval practice opportunities in my lesson plans for this new academic year. Following on from RQ1, I will also think more critically about how each retrieval activity can be most effectively used in lesson time. Whilst retrieval practice helps

students to retain knowledge that they have learned recently, some activities such as the concept mapping require the student to have a fairly broad subject knowledge prior to attempting retrieval in this way (Soderstrom *et al*., 2016; Francis *et al*., 2020).

During my teaching career, I have also taught GCSE Biology and GCSE Chemistry. The specification that our school follows, particularly for GCSE Chemistry, requires lots of information to be learned early on in the course so that that it can be built upon later. For example, initially learning about atoms and types of bonding, so that ultimately students can explain properties of matter. Retrieval practice would be helpful to constantly remind students of the fundamentals and build up their subject knowledge. Quick recall would allow them to apply knowledge to new situations (Karpicke and Grimaldi, 2012). GCSE Biology is slightly different as there are more independent topics to cover. For instance, photosynthesis and labelling the eye are quite unrelated. It is therefore easy for students to forget information because it might not be covered again until exam time. This is alongside the fact that information is forgotten quickly in line with Ebbinghaus' forgetting curve (Murre and Dros, 2015). Thus, in GCSE Biology it would be beneficial to regularly retrieve information from other topics to prevent it from being forgotten. Additionally, by recalling information from another topic it may act as a 'change in context' much like in the Pastötter *et al.,* (2011) study. The change in topic acts as a 'reset' so that each topic has its own memory cues and is better retained and recalled.

My School Setting

The recent appointment of a teaching and learning lead is part of a whole school drive to '*provide inspirational teaching*'. Because of this, I am able to share my research with her and disseminate it through her, to the rest of the school via CPD sessions on inset day or informal chats. The implications of this research will be that I can support her in introducing more retrieval practice in school, especially within my department. This should have the effect of improving student attainment by equipping them with better study habits. Furthermore, I am now better qualified to

offer advice to those parents and guardians who ask at parent's evening '*how can I help my child revise?*'.

Wider Educational Context

In June 2022, I presented my findings at the University of Oxford Education Department's poster conference. This was attended by current Part 2 and Part 3 Masters in Learning and Teaching students. I feel that it was received well as I was able to answer questions about the study and explain my findings. There were several Part 2 students who were interested in retrieval practice too so it was fascinating to hear about their initial thoughts for their project and justify parts of my project. Moreover, there were other Part 3 students who had also explored the use of retrieval practice in different subject areas so it was great to talk to them and share findings and thoughts.

Collaboration

Over the course of this investigation, all of the retrieval resources were shared with the two other members of my department. I chose to share with these colleagues as they both teach A-Level biology in addition to KS3 and KS4 biology. I felt that they would give honest feedback on Biology specific resources. As a result of their input, I have also created and shared more resources which are applicable to more age groups than just A-Level. Those which are generic retrieval activities, and not subject specific, have also been shared with the Teaching and Learning lead. These have then been uploaded onto the teaching and learning Google Classroom page so that all teaching staff in the school can access them. One comment on the Google Classroom page containing the retrieval resources was from a teacher expressing concern that these activities '*may take time away from learning, especially when time is already limited at KS4/5'.* Whilst I understand this concern, it shows a real need for the benefits of retrieval practice to the learning process to be shared more widely amongst teachers in my school (and beyond). In response to the aforementioned comment, the Teaching and Learning lead explained '*I promise once they become routine, they are so easy and our pupils are really adaptive*'.

The two other teachers within my department were both interested in the research surrounding retrieval practice as they do not regularly engage with educational research. My Head of Department was stunned at how quickly information is forgotten and said '*no wonder they look blankly at me at the start of a new lesson*'. I enjoyed summarising papers that I had read as part of this study and disseminating the important information to my departmental colleagues. This usually occurred as an informal chat in the staffroom, or conversation when they were politely asking about the progress of this investigation. I learned that people are more interested in the findings from the literature than I initially thought, but they just do not feel they have the time or knowledge on where to access the information.

As mentioned previously, I chose to only conduct this investigation on my A-Level students as the other Year 13 class only had five students in it. I felt that the teaching and embedding of the retrieval practice would have been too different from my own class of 21 to make it comparable. Therefore, the data collection for this investigation was not as collaborative as I had initially hoped. However, both my Head of Department and the Teaching and Learning lead were particularly interested in the findings that students are still using ineffective study strategies. This was something that all three of us were quite passionate about addressing. My Head of Department actually seemed quite annoyed that students were using techniques such as re-reading and re-writing notes to revise. She said '*I print off all of these past papers for them to complete but they always insist on making their notes look pretty first. They basically re-write the textbook. They think they learn that way but I think it just makes them feel better*'. This is in line with the literature's comments that re-reading leads to overfamiliarity with the text that is mistaken, by students, for retention of information (Karpicke *et al*., 2009). Or in other words, metacognitive illusion (Bjork *et al*., 2013). I passed my findings to the Teaching and Learning lead. She said that she would include my opinions on different retrieval activities and the suggestions that retrieval practice improves attainment in her CPD session on our September INSET day. We also agreed it would be important for the next academic year to spend time with the students, across all departments, explaining how best to learn

and revise. However, no firm plan of action has been agreed upon as yet. I would like to collaborate more as I think it is really valuable. So, although there has been fairly limited collaboration on this investigation, sharing the findings has opened up dialogue between different teaching staff and departments about what can be done going forward.

References

Agarwal, P. K., & Roediger, H. L. (2019). Lessons for learning: How cognitive psychology informs classroom practice. Phi Delta Kappan, *100*(4), 8-12. https://doi.org/10.1177/0031721718815666

Agarwal, P. K., Nunes, L. D., & Blunt, J. R. (2021). Retrieval Practice Consistently Benefits Student Learning: a Systematic Review of Applied Research in Schools and Classrooms. *Educational Psychology Review*, *33*(4), 1409-1453. https://doi.org/10.1007/s10648-021-09595-9

Atkinson, R. C., & Shiffrin, R. M. (1968). Human Memory: A Proposed System and its Control Processes. *The Psychology of Learning and Motivation, 2*, 89-195. https://doi.org/10.1016/S0079-7421(08)60422-3

Bjork, R. A. (1999). Assessing our own competence: Heuristics and illusions. In D. Gopher & A. Koriat (Eds.). *Attention and performance XVII. Cognitive regulation of performance: Interaction of theory and application,* 435-459. Cambridge, MA: MIT Press.

Bjork, R. A., Dunlosky, J., & Kornell, N. (2013). Self-Regulated Learning: Beliefs, Techniques, and Illusions. *Annual Review of Psychology*, *64*(1), 417-444. https://doi.org/10.1146/annurev-psych-113011-143823

Blunt, J. R. & Karpicke, J. D. (2014). Learning with retrieval-based concept mapping. *Journal of Educational Psychology*, *106*(3), 849–858. https://doi.org/10.1037/a0035934

Braun, V. & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77-101. https://doi.org/10.1191/1478088706qp063oa

British Educational Research Association [BERA]. (2018). *Ethical Guidelines for Educational Research*, fourth edition, London. https://www.bera.ac.uk/publication/ethical-guidelines-for-educational-research-2018-online [accessed 18th February, 2022]

Butler, A. C., Marsh, E. J., Goode, M. K., & Roediger III, H.,L. (2006). When additional multiple-choice lures aid versus hinder later memory. *Applied Cognitive Psychology, 20*(7), 941-956. https://doi.org/10.1002/acp.1239

Carpenter, S. K. (2009). Cue strength as a moderator of the testing effect: The benefits of elaborative retrieval. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *35*(6), 1563–1569. https://doi.org/10.1037/a0017021

Cervin-Ellqvist, M., Larsson, D., Adawi, T., Stöhr, C., & Negretti, R. (2020). Metacognitive illusion or self-regulated learning? Assessing engineering students' learning strategies against the backdrop of recent advances in cognitive science. *Higher Education, 82*(3), 477-498. https://doi.org/10.1007/s10734-020-00635-x

Dunlosky, J., Rawson, K. A., Marsh, E. J., Nathan, M. J., & Willingham, D. T. (2013). Improving Students' Learning With Effective Learning Techniques: Promising Directions From Cognitive and Educational Psychology. Psychological Science in the Public Interest, *14*(1)

Farrimond, H., 2017. The Ethics of Research. In D. Wyse, N. Selwyn, E. Smith, & L. Stuter (Eds.). *The BERA/SAGE Handbook of Educational Research*, 72-89. London: Sage Publications

Finkenbinder, E.O. (1913). The curve of forgetting. The American Journal of Psychology 24: 8-32.

Firth, J. (2020). *The teacher's guide to research: engaging with, applying and conducting research in the classroom*. Routledge.

Francis, A. P., Wieth. M. B., Zabel, K. L., & Carr. T, H. (2020). A Classroom Study on the Role of Prior Knowledge and Retrieval Tool in the Testing Effect. *Psychology, Learning & Teaching*, *19*(3), 258-274. https://doi:10.1177/1475725720924872

Gates, A. I. 1. (1917). *Recitation as a factor in memorizing, by Arthur I. Gates*. New York (State).

Gog, T., & Sweller, J. (2015). Not New, but Nearly Forgotten: the Testing Effect Decreases or even Disappears as the Complexity of Learning Materials Increases. *Educational Psychology Review, 27*(2), 247-264. https://doi.org/10.1007/s10648-015-9310-x

James, W. (1890). *The principles of psychology*. New York: Holt

Jones, K. (2019). *Retrieval Practice : Research & Resources for every classroom*. John Catt Educational Ltd.

Jones, K. (2021). *Retrieval Practice : Resource guide*. John Catt Educational Ltd.

Kang, S. H. K., Lindsey, R. V., Mozer, M. C., & Pashler, H. (2014). Retrieval practice over the long term: Should spacing be expanding or equal-interval? *Psychonomic Bulletin & Review, 21*(6), 1544-1550. https://doi.org/10.3758/s13423-014-0636-z

Karpicke, J. D., & Roediger III, H.,L. (2007). Expanding retrieval practice promotes short-term retention, but equally spaced retrieval enhances long=term retention. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *33*, 704-719. https://doi:10.1037/02787393.33.4.704

Karpicke, J. D., Butler, A. C., & Roediger III, H.,L. (2009). Metacognitive strategies in student learning: Do students practise retrieval when they study on their own? *Memory (Hove*), *17*(4), 471-479. https://doi.org/10.1080/09658210802647009

Karpicke, J. D., & Grimaldi, P. J. (2012). Retrieval-Based Learning: A Perspective for Enhancing Meaningful Learning. *Educational Psychology Review, 24*(3), 401-418. https://doi.org/10.1007/s10648-012-9202-2

Karpicke, J. D. (2012). Retrieval-Based Learning: Active Retrieval Promotes Meaningful Learning. *Current Directions in Psychological Science : A Journal of the American Psychological Society, 21*(3), 157-163. https://doi.org/10.1177/0963721412443552

Landauer, T.K., & Bjork, R.A. (1978). Optimum rehearsal patterns and name learning. In M.M. Gruneberg, P.E. Morris & R.N. Sykes (Eds.), *Practical aspects of memory* (pp.625-632). London: Academic Press.

Lindeke, L.L., Hauck, M.R., & Tanner, M. (2000). Practical issues in obtaining child assent for research. *Journal of Pediatric Nursing,* 15(2), 99-104.

Logan, J. M., & Balota, D.A. (2008). Expanded vs. equal interval spaced retrieval practice: Exploring different schedules of spacing and retention interval in younger and older adults. *Aging, Neuropsychology and Cognition, 15*, 257-280. doi:10.1080/13825580701322171

Minear, M., Coane, J. H., Boland, S. C., Cooney, L. H., & Albat, M. (2018). The Benefits of Retrieval Practice Depend on Item Difficulty and Intelligence. *Journal of Experimental Psychology.Learning, Memory, and Cognition, 44*(9), 1474-1486. https://doi.org/10.1037/xlm0000486

Moscovitch, M. (2007). Memory: Why the engram is elusive. In H.L. Roediger, Y. Dudai, &S.M. Fitzpatrik (Eds.), *Science of memory: Concepts* (pp. 17-21). New York, NY: Oxford University Press.

Murre, J. M. J., & Dros, J. (2015). Replication and analysis of Ebbinghaus' forgetting curve. *PloS One, 10*(7), e0120644. https://doi.org/10.1371/journal.pone.0120644

Nelson, T. O., & Narens, L. (1990). A Theoretical Framework for Metamemory. *The Psychology of Learning and Motivation, 26*, 125.

Pastötter, B., Bäuml, K., & Hanslmayr, S. (2008). Oscillatory brain activity before and after an internal context change — Evidence for a reset of encoding processes. *NeuroImage (Orlando, Fla.), 43*(1), 173-181. https://doi.org/10.1016/j.neuroimage.2008.07.005

Pastötter, B., Schicker, S., Niedernhuber, J., & Bäuml, K.,T. (2011). Retrieval during learning facilitates subsequent memory encoding. *Journal of Experimental Psychology.Learning, Memory, and Cognition, 37*(2), 287-297. https://doi.org/10.1037/a0021801

Radossawljewitsch, P.R. (1907). Das Behalten und Vergessen bei kindern und Erwachsenen nach experimentellen Untersuchungen [An experimental investigation of the retention and forgetting among children and adults] Leipzig: Nemnich.

Rhodes, M. G. (2019). Metacognition. *Teaching of Psychology, 46*(2), pp168-175. https://doi.org/10.1177/0098628319834381

Roediger, H. L. (1985). Remembering Ebbinghaus. *Contemporary Psychology, 30*(7), 519-523. https://doi.org/10.1037/023895

Roediger, H. L., III, & Marsh, E. J. (2005). The positive and negative consequences of multiple-choice testing. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*(5), 1155–1159. https://doi.org/10.1037/0278-7393.31.5.1155

Roediger, H. L., & Karpicke, J. D. (2006a). The Power of Testing Memory: Basic Research and Implications for Educational Practice. *Perspectives on Psychological Science, 1*(3), 181-210. https://doi.org/10.1111/j.1745-6916.2006.00012.x

Roediger, H. L., & Karpicke, J. D. (2006b). Test-Enhanced Learning: Taking Memory Tests Improves Long-Term Retention. *Psychological Science*, *17*(3), 249-255. https://doi.org/10.1111/j.1467-9280.2006.01693.x

Rowland, C. A. (2014). The Effect of Testing Versus Restudy on Retention: A Meta-Analytic Review of the Testing Effect. *Psychological Bulletin, 140*(6), 1432-1463. https://doi.org/10.1037/a0037559

Sederberg, P. B., Gauthier, L. V., Terushkin, V., Miller, J. F., Barnathan, J. A., & Kahana, M. J. (2006). Oscillatory correlates of the primacy effect in episodic memory. NeuroImage (Orlando, Fla.), 32(3), 1422-1431. https://doi.org/10.1016/j.neuroimage.2006.04.223

Soderstrom, N. C., Kerr, T. K., & Bjork, R. A. (2016). The Critical Importance of Retrieval—and Spacing—for Learning. *Psychological Science, 27*(2), 223-230. https://doi.org/10.1177/0956797615617778

Smith, M. A., & Karpicke, J. D. (2014). Retrieval practice with short-answer, multiple-choice, and hybrid tests. Memory (Hove), 22(7), 784-802. https://doi.org/10.1080/09658211.2013.831454

Tai, J., Ajjawi, R., Boud, D., Dawson, P., & Panadero, E. (2018). Developing evaluative judgement: enabling students to make decisions about the quality of work. *Higher Education*, *76*(3), 467-481. https://doi.org/10.1007/s10734-017-0220-3

Thomas, G. (2017). *How to do your research project: a guide for students* (Third ed.). SAGE.

Appendix A

Participant questionnaire adapted from Cervin-Ellqvist *et al.,* (2020).

Question 1
What strategies do you use when you study for a biology exam? List all strategies you use and rank-order them from the ones you use the most often to the ones you use the least often.

Question 2
Explain for each one of your three most used strategies why you use them.
(If you listed fewer than three strategies, explain for the ones you listed).

Question 3
Answer the question by following the two steps below. If you have any comments, there is space to write them at the bottom of the page.

1) Read the strategies carefully and tick the ones you use in Biology.
2) How effective do you think the strategies you ticked are to learn what may be examined in Biology? Circle one number for each of the strategies you use.

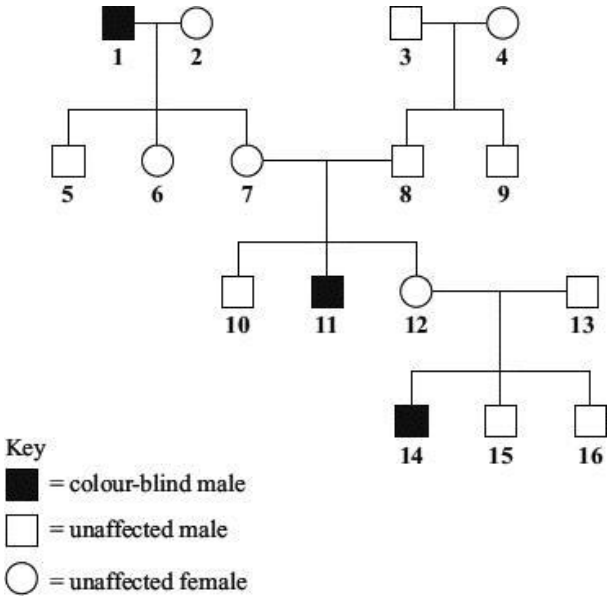
I use this strategy						
	Identify/come up with keywords and create mental images of those to remember/learn the information linked to keywords.	Not helpful	1	2	3	Very helpful
	Write summaries.	Not helpful	1	2	3	Very helpful
	Check what you know of the course content by testing yourself on it.	Not helpful	1	2	3	Very helpful
	Read course material and/or your own notes more than once.	Not helpful	1	2	3	Very helpful
	Highlight or underline in books or notes.	Not helpful	1	2	3	Very helpful
	Try to explain to oneself why facts or concepts are true/correct.	Not helpful	1	2	3	Very helpful
	Try to explain to oneself how new information is related to old, or explain the different steps taken when solving a problem/ a task	Not helpful	1	2	3	Very helpful
Additional comments:						

Appendix B

The past paper exam questions which were completed by participants.

Q1.

Red-green colour blindness is caused by a mutation in the gene coding for one of the opsin proteins which are needed for colour vision. The diagram shows the inheritance of red-green colour blindness in one family.



Person **12** is pregnant with her fourth child. What is the probability that this child will be a male with red-green colour blindness? Explain your answer by drawing a genetic diagram. Use the following symbols

X^R = an X chromosome carrying an allele for normal colour vision

X^r= an X chromosome carrying an allele for red-green colour blindness

Y = a Y chromosome

Probability = _____

(Total 4 marks)

Q2.

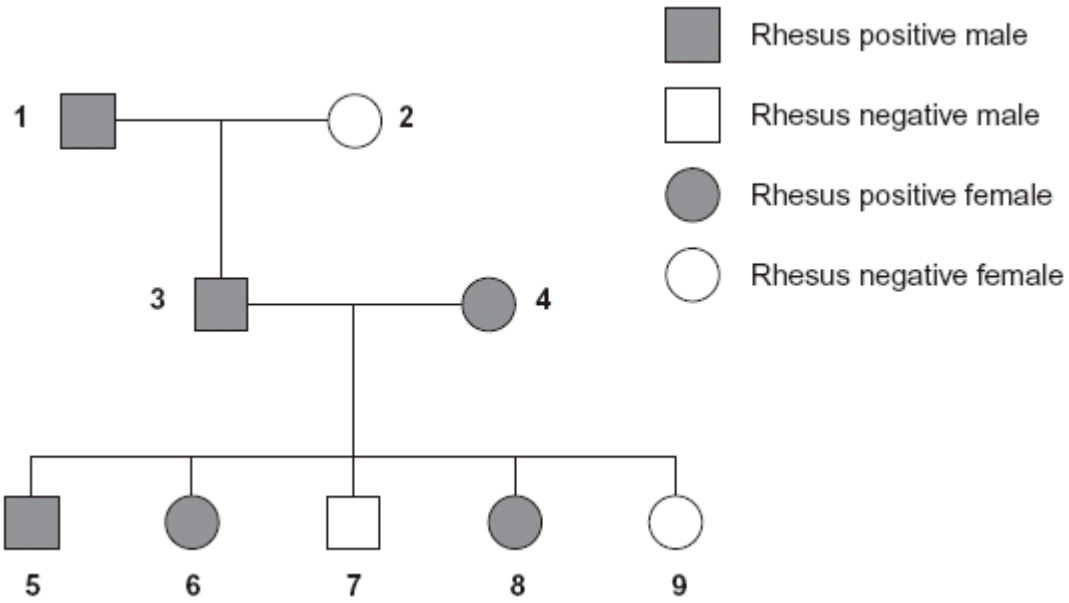
(a) (i) Explain what is meant by a **recessive** allele.

(1)

(ii) Explain what is meant by **codominant** alleles.

(1)

(b) The Rhesus blood group is genetically controlled. The gene for the Rhesus blood group has two alleles. The allele for Rhesus positive, **R**, is dominant to that for Rhesus negative, **r**. The diagram shows the inheritance of the Rhesus blood group in one family.



(i) Explain **one** piece of evidence from the diagram which shows that the allele for Rhesus positive is dominant.

(2)

(ii) Explain **one** piece of evidence from the diagram which shows that the gene is **not** on the X chromosome.

(2)

(c) Sixteen percent of the population of Europe is Rhesus negative. Use the Hardy-Weinberg equation to calculate the percentage of this population that you would expect to be heterozygous for the Rhesus gene.

Show your working.

Answer _____

(3)
(Total 9 marks)

Q3.

A breeder crossed a black male cat with a black female cat on a number of occasions. The female cat produced 8 black kittens and 4 white kittens.

(a) (i) Explain the evidence that the allele for white fur is recessive.

(1)

(ii) Predict the likely ratio of colours of kittens born to a cross between **this** black male and a white female.

(1)

(b) The gene controlling coat colour has three alleles. The allele **B** gives black fur, the allele **b** gives chocolate fur and the allele $\mathbf{b^i}$ gives cinnamon fur.

- Allele **B** is dominant to both allele **b** and $\mathbf{b^i}$.
- Allele **b** is dominant to allele $\mathbf{b^i}$.

(i) Complete the table to show the phenotypes of cats with each of the genotypes shown.

Genotype	Phenotype
$\mathbf{Bb^i}$	
$\mathbf{bb^i}$	
Bb	

(1)

(ii) A chocolate male was crossed several times with a black female.

They produced

- 11 black kittens
- 2 chocolate kittens
- 5 cinnamon kittens.

Using the symbols in part (b), complete the genetic diagram to show the results of this cross.

*Parental phenotype*s Chocolate male Black female

Parental genotypes _____ _____

Gametes _____ _____

Offspring

genotypes _____ _____ _____

Offspring phenotypes Black Chocolate Cinnamon **(3)**

(iii) The breeder had expected equal numbers of chocolate and cinnamon kittens from the cross between the chocolate male and black female. Explain why the actual numbers were different from those expected.

(1)

(iv) The breeder wanted to produce a population of cats that would all have chocolate fur. Is this possible? Explain your answer.

(2)

(Total 9 marks)

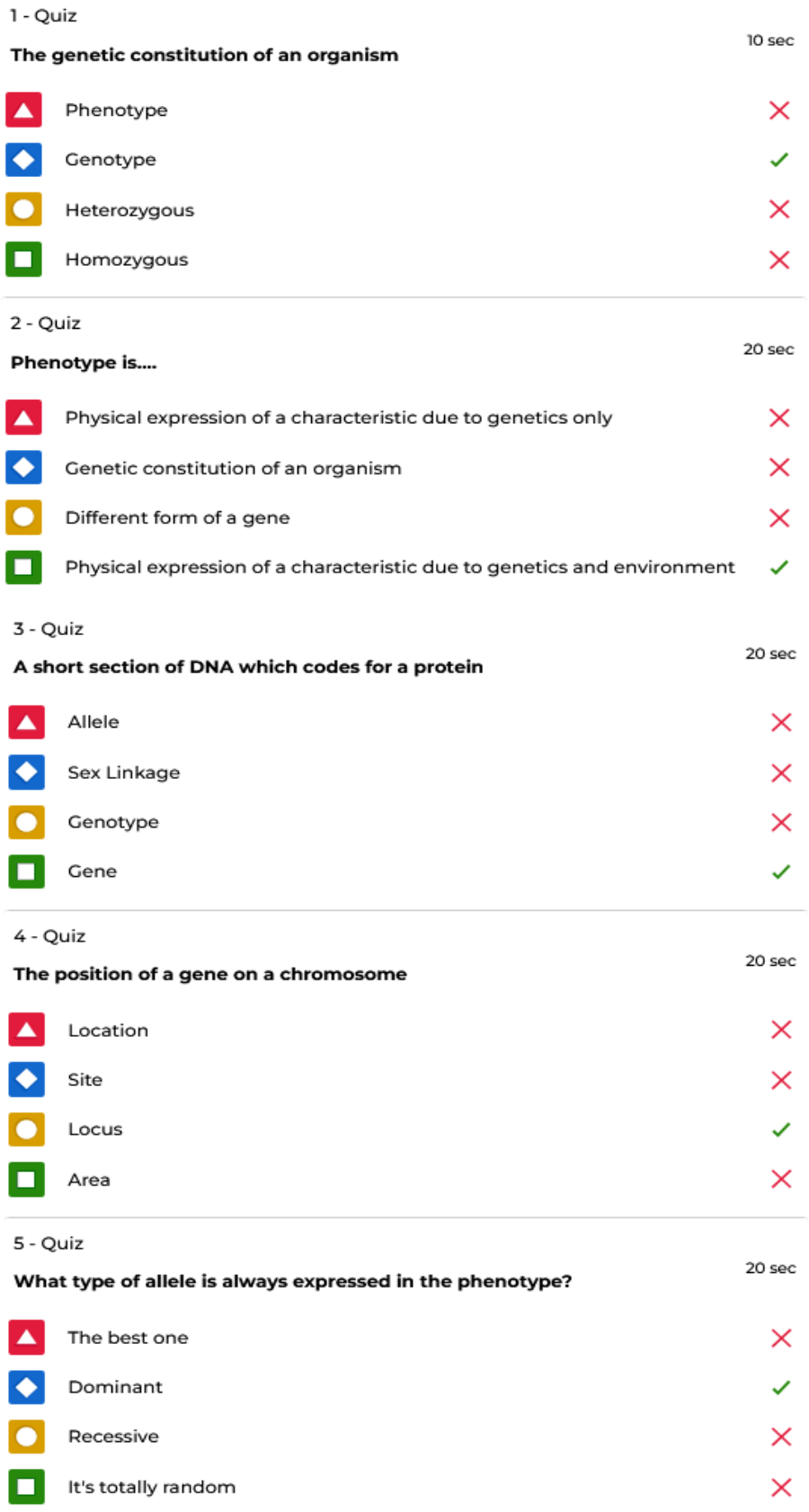
Appendix C

A copy of the retrieval reflection ticket used (adapted from Jones, 2021).

Areas of strength/confident recall	Gaps in knowledge

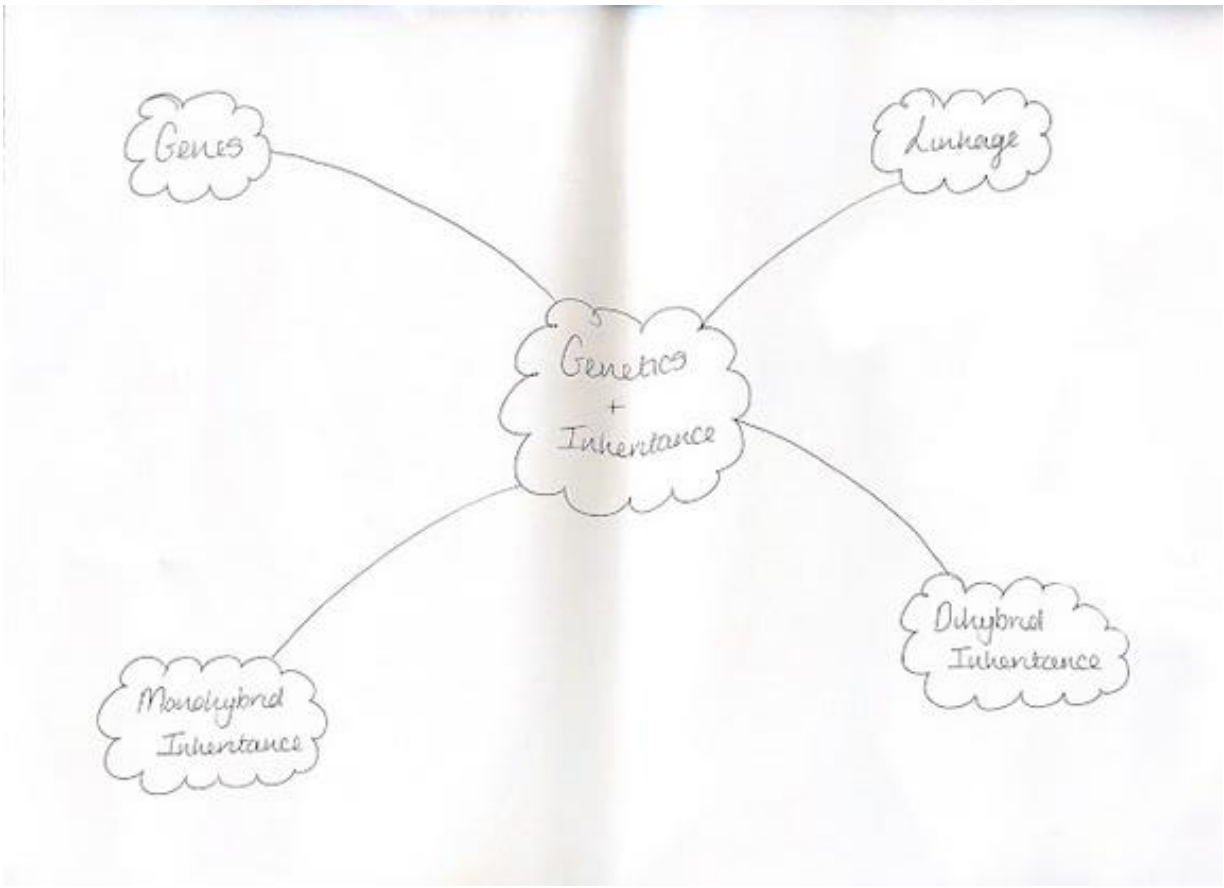
Appendix D

A selection of some of the questions on the Kahoot quiz.



Appendix E

A copy of the concept map given to students.



Appendix F

A copy of the research consent letter sent to the school's Head Teacher

UNIVERSITY OF OXFORD
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general.enquiries@education.ox.ac.uk www.education.ox.ac.uk

Director Professor Jo-Anne Baird

[redacted]

Dear [redacted]

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 [redacted] In my final research project *"Using retrieval practice as a tool to improve attainment in KS5 Biology"* I will explore how to better integrate retrieval practice into the teaching a learning process and assess its impact on student learning and recall.

The research will take place with two Upper 6th Biology classes working towards their A Level. Research within the educational literature shows that retrieval practice can have a huge impact on the learning process as well as the obvious ability to quickly recall facts. I hope to find out what study techniques students are currently using to prepare for examinations and then explain how retrieval practice may help them to retain more information. I will then introduce a series of different retrieval practise techniques to them during lesson time. I will assess how they perform on some exam style questions, comparing their results from before the techniques were introduced with their performance on the same questions after the techniques were introduced.

By participating in the research, the school would be contributing to a project that will improve our understanding of how A Level students tackle their revision. If students can be encouraged to partake in more active revision (rather than passive re-reading of notes), then they should be able to retain more information and answer exam questions more confidently. This should improve their attainment in exam situations and empower them with useful study skills that will benefit their future education.

I hope to conduct this research between December 2021 and March 2022. I would like to use a questionnaire to gain student perspectives on the study techniques that they use and how effective they perceive those techniques to be. I would also like to assess their attainment on some exam questions before and after the introduction of specific retrieval practice techniques.

Oxford University has strict ethical procedures on conducting ethical research, consistent with current British Educational Research Association guidelines. The University also recognises, however, that my study is a piece of practitioner research, and that schools already operate with the highest ethical standards. 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, [redacted] and me, and only used for academic purposes. It will be kept for as long as it has academic value.

If you are happy for me to proceed with this study, please confirm that using the attached reply form. If you have any concerns or need more information about what is involved, please contact me or my supervisor. Further, if you

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Director Professor Jo-Anne Baird

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

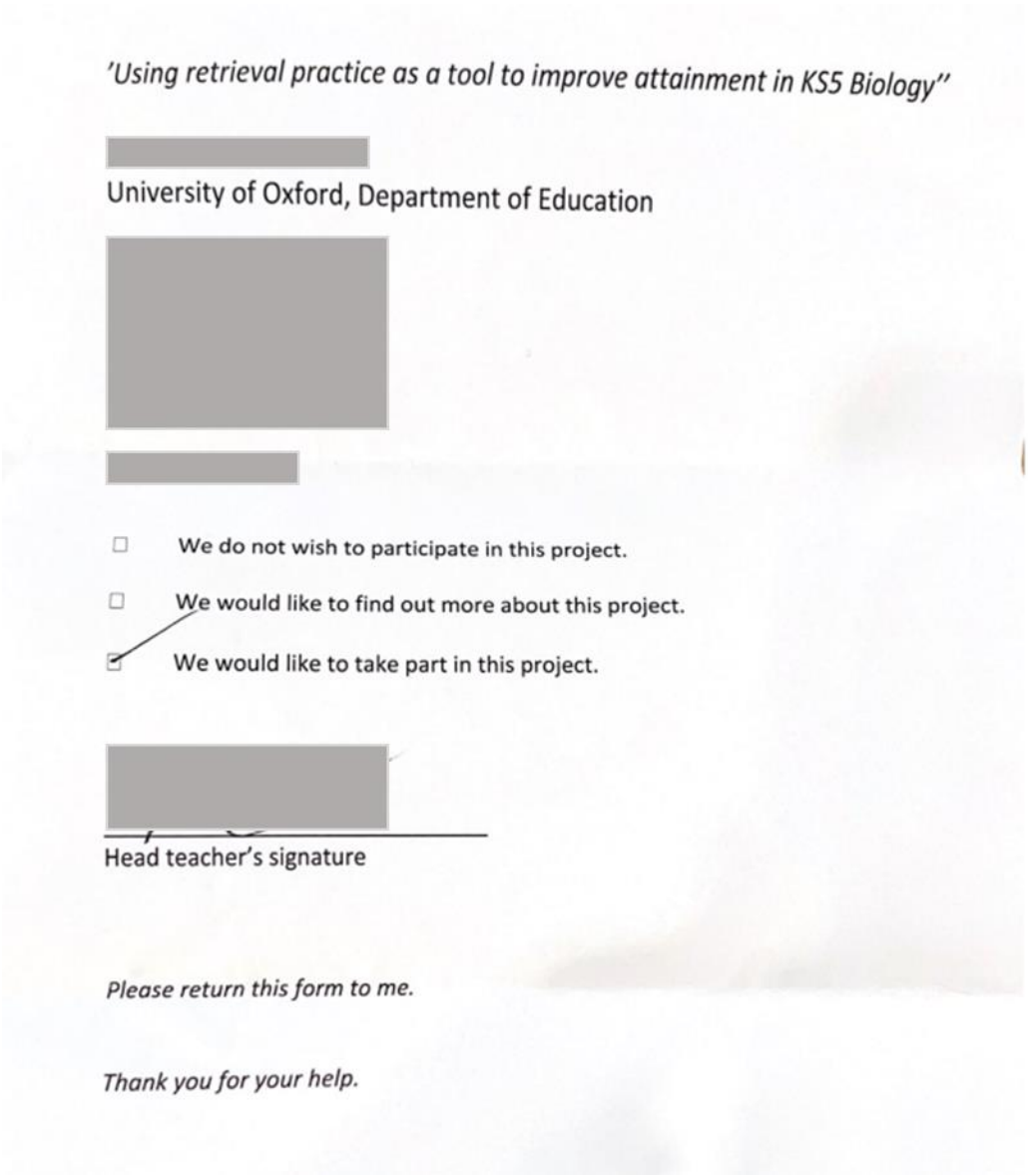
I look forward to hearing from you.

Yours sincerely,

[redacted]

Appendix G

A copy of the research consent reply slip completed by the school's Head Teacher



'Using retrieval practice as a tool to improve attainment in KS5 Biology''

[redacted]

University of Oxford, Department of Education

[redacted]

[redacted]

☐ 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.

[redacted]

Head teacher's signature

Please return this form to me.

Thank you for your help.

Appendix H

A table to show the pre-RP and post-RP test scores achieved by each student completing the past paper exam questions.

Student	Pre-RP score	Post-RP score	Change in score
A	11	17	6
B	8	17	9
C	8	17	9
D	4	10	6
E	14	22	8
F	11	22	11
G	16	22	6
H	8	9	1
I	2	21	19
J	11	21	10
K	3	10	7
L	4	13	9
M	3	14	11
N	6	21	15
O	11	13	2
P	8	18	10
Q	11	21	10
R	14	20	6
S	2	14	12
T	8	19	11
U	5	13	8
Average	8.0	16.9	8.9

Appendix I

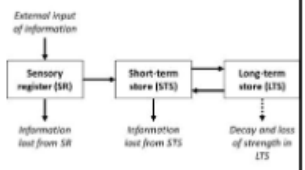
Slides produced to show Year 9 students some research surrounding retrieval practice and advice on how to revise.

How we learn… and how to revise.

How are memories made?

- Visual stimuli are only accurately stored in the SR for several hundred milliseconds.
- Information stored in short-term storage for 15-30 seconds.
- Information can then move to the long-term store where it remains relatively permanently but can be modified.
- Rehearsal of information increases the strength of storage in the LTS otherwise this information may be lost over time.
- Information that is regularly selected for is maintained in the LTS, as it passes back and forth between the STS and the LTS.

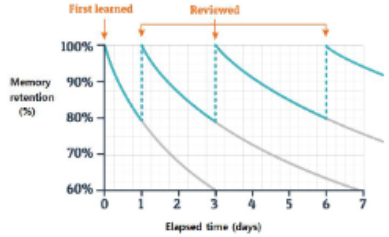
Memories decay if they are not used. They are strengthened if they are used.



The forgetting curve



Overcoming the forgetting curve



How do you revise currently?

- Re-read notes
- Highlight notes
- Write out new notes
- Summarise notes
- Test yourself
- Get someone else to test you
- Practice exam questions

How do you revise currently?

- Re-read notes
- Highlight notes
- Write out new notes
- Summarise notes
- Test yourself
- Get someone else to test you
- Practice exam questions

→ The techniques in red are the best ones for revision.
→ They are ACTIVE.
→ They force your brain to do something.
→ They test if you actually know the information.
→ If you re-read notes too much you become 'fluent' in reading… this makes you think you know it… you do not.
→ Testing yourself provides 'desirable difficulties' that forces you to think about retrieving information stored in your mind. It strengthens your memory.
→ Testing yourself also allows you to identify what you don't know so that you can focus on that.