2019 cohort

Sally Malik – Maths Teacher

Practice Makes Perfect: Getting Maths to Stick Through Retrieval Practice

The requirement of mathematics in science

Understanding and engaging with mathematics is a fundamental part of any pupil's science education and paves the way for a fulfilling career in a wide range of STEM professions [1]. However, pupils regularly perceive mathematics to be difficult [2], many acquiring a defeatist attitude and simply believe "it is ok—not everyone can be good at math" [3].

As classroom practitioners we simply cannot let this attitude manifest. Mathematical skills make up 20% of marks awarded for the combined science GCSE [4]. For the single science GCSEs, marks for mathematical skills make up a minimum of 10% in biology; 20% in chemistry; and 30% in physics [4]. Therefore, to achieve top grades in their science GCSEs, pupils not only have to be accomplished scientists but also proficient mathematicians.

The problem with mathematics in science

The science curriculum is content heavy, with pupils required to remember and apply a large amount of knowledge in their GCSE examinations. Time pressures of delivering the high knowledge content of the science curriculum can mean that pupils fail to achieve mastery in mathematics problems. Information has not had the required time to be processed and transferred into the long-term memory, where it can be recalled later [5]. Pupils quickly forget how to answer science-based mathematics problems and fail to recall and rearrange equations.

Promoting remembering with retrieval practice

It would be logical to hypothesise that incorporating more opportunities for practice of mathematical problems in the science classroom would lead to enhanced understanding and retention of these concepts. "Practice makes perfect" has long been highly regarded in the field of neuroscience, with repetition or practice of a skill leading to increased myelination of nerve fibres [6]. The speed at which nerve impulses are transmitted are enhanced resulting in improved progress and attainment of that repeated or practiced skill [6]. This can be accomplished through retrieval practice, a highly regarded and successful evidence-based strategy requiring pupils to recall knowledge from their memory with little or no support [7]. Retrieval practice incorporates

"desirable difficulties" into the classroom, aiding knowledge retention and improves learning [8]. Through retrieval practice, information is more likely to be transferred into the long-term memory, thus strengthening pre-existing schema [9] and has been shown to facilitate mastery of new information [10].

Evidence suggests that testing via retrieval practice can lead to a 21% increase in final assessment scores [11], significantly more effective than rereading [12] restudy [11], note-taking [13] or even elaborative study [14]. This is because these study techniques lead only to short-term learning, with information not being transferred for storage and recall in the long-term memory [7].

Studies have shown that practicing mathematics problems after a delay can significantly increase long-term knowledge retention [15-17] by increasing storage strength [18]. This spacing introduces an element of forgetting thereby increasing the level of desirable difficulties [8].

Implementing maths retrieval practice in the science classroom

So as not to impact significantly on teaching time, which is already at a premium in the science classroom it is suggested here that retrieval practice take the form of a low-stakes quiz. This format has been shown to significantly enhance performance in end of topic and end of unit assessments [19-20]. In a meta-analysis of 222 independent studies, retrieval practice via class quizzing consistently enhanced academic performance by approximately 83% [21].

A five-minute quiz can be given to pupils at the beginning of each science lesson. For maximum impact, the quiz should be followed by feedback, so pupils understand what they know and the gaps in their knowledge. Immediate feedback can also increase knowledge transfer to different contexts [22], for example between maths and science. Retrieval practice quizzes should be designed to test skills covered in the previous lesson (2 questions) and prior learning (3 questions), to incorporate the benefits of spaced practice.

Assessing impact

It is advised that any practitioner wishing to implement a maths retrieval practice intervention in their classroom assesses its impact on pupil progress and attainment in the following ways:

1. Pupils sit a pre- and post-intervention maths assessment.

This allows comparison of maths ability at the start and end of the intervention to determine the overall effect of the retrieval practice intervention on knowledge retention and recall. A control class with similar demographics and range of abilities should be chosen, that would also take the pre- and post-intervention assessment but not take part in the retrieval practice intervention. This should ensure that any enhanced testing effect observed is due to the retrieval practice intervention and not due to familiarity of the assessment.

2. *Pupils answer a pre- and post-intervention questionnaire.*

Pupil's feelings, experiences and/or perceptions of the retrieval practice intervention can be assessed via a questionnaire. They are also useful tools in uncovering factors hampering pupil progress and attainment that would missed if relying only on quantitative data alone. For example, many pupils suffer from "maths-anxiety", a debilitating and often psychologically routed problem severely effecting self-efficacy [23]. However, retrieval practice has been shown to reduce end of unit test and exam anxiety by 71% [24], therefore, it could be envisaged that maths-anxiety may also be diminished.

In addition, interviewing some pupils may elicit a fuller picture of their views, beliefs attitudes and opinions of the retrieval practice intervention.

Next steps

Previous studies have shown that for low attaining pupils, answering multiple-choice questions led to a subsequent testing effect which was lacking for the high attaining pupils [25]. Interestingly, performance of all pupils was negatively affected when elaborative interrogation questions were set. Other studies have explored whether designing retrieval quizzes based on areas of weak performance in prior exams could lead to a greater testing effect [26]. Therefore, it would be prudent to investigate if and how the testing effect varies depending upon pupil ability and how the quiz design might also influence the outcomes of the intervention.

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