The design of 'Numeracy Mats' as a visual aid and model of self-questioning to support memory retention and self-regulation strategies.

Emma Bishop

Ysgol Bryn Elian

This strand of design research is part of an on-going study that aims to evaluate the impact of domain specific self-questioning prompts and regular exposure to common mathematical methods and formulae in the form of 'Numeracy Mats'. The motivation came from observing a Year 10 Set 1 class struggling to make mathematical connections and on occasions failing to recall the necessary methods or formulae when tackling GCSE Numeracy problems (WJEC).

The concept of the mats are based on the theory of metacognition and its influence on problem solving. Important mathematical information was connected on the mats by questions that model a self-regulatory approach to arriving at the methods or formulae needed to calculate solutions. The colour and font on the mats was considered as these have been found to influence the recall of learnt information.

The mats are currently implemented in the classroom and referred to on a daily basis.

numeracy, maths, mathematics, GCSE, wales, metacognition, self-questioning, self-regulation, long-term, memory, re-call, retention, metacognitive, awareness, inventory

Introduction and background

In 2009 and 2012 (and later in 2015), Wales performed significantly lower than average in the Programme for International Student Assessment (PISA) (National Assembly for Wales, 2013), sparking a national debate on the quality and future of the country's education. In 2012 30% of the 15-year-olds who participated in the assessments failed to achieve Level 2 in Mathematics, which the OECD (2014) claim is the "baseline of proficiency at which students begin to demonstrate competencies to actively participate in life" (p.3). This acted as the catalyst for fundamental reform across the curriculum, but perhaps the most radical was the changes to GCSE Mathematics qualifications in Wales. The changes included a revised Mathematics GCSE and the introduction of a unique Numeracy GCSE with the intention for the latter to focus teaching and learning on the skills required in the PISA assessments.

In order to assess the types of mathematical skills that are necessary for cross-curricular study, work and everyday life, the Numeracy papers pose all questions in real-life context, an aspect believed to be lacking in the previous qualification. The ability to access and apply Mathematics and apply it in real-world situations and therefore succeed in the Numeracy type questions relies on a student's level of 'Mathematical Literacy'. Mathematical Literacy has been defined as;

> an individual's capacity to formulate, employ, and interpret mathematics in a variety of contexts. It includes reasoning mathematically and using mathematical concepts, procedures, facts and tools to describe, explain and predict phenomena. It assists individuals to recognise the role that mathematics plays in the world and to make the well-founded judgments and decisions needed by constructive, engaged and reflective citizens. (OECD, 2013, p.5)

Mathematical literacy skills are considered by the OECD to be on a "continuous, multidimensional spectrum ranging from aspects of basic functionality to high-level mastery" (de Lange, 2006, p.16). Many pupils therefore experience difficulties solving intra- and extra-mathematical problems within a variety of domains as the ability to do so is a higher-order skill. The numeracy papers also pose problems for those studying Mathematics with English as an Additional Language, Additional Learning Needs such as dyslexia and generally poor literacy skills. This is due to the extent of reading and comprehension required to elicit the necessary mathematical method required to solve the Numeracy problems. Despite this, discrepancies between Mathematics and Numeracy A* to C grades over the first three cycles has not been significant, which suggests that there is isn't a glaringly obvious problem with pupils' abilities to access the questions. However, from my experience in the classroom, the stress that is caused by the cognitive overload perceived by pupils when answering these questions, leads to heightened anxiety, erratic 'all or nothing' approaches and an inability to recall key methods and/or formulae. This is particularly the case for a Year 10 Set 1 class that will be sitting their Numeracy GCSE Examination early in November 2018. They all have above average reading and comprehension levels and have proved consistently over the last four years that they can problem solve and think 'outside the box' through a number of mathematical projects and problem solving tasks. They also show through formative assessment that they can carry out mathematical procedures once shown or discovered and they are confident in their ability to deal and work with numbers. However, if the required method is not instantly identifiable or they are unable to make a link through visual representation immediately, they become frustrated. This frustration often turns into worry and panic and in a classroom environment, even when prompted in the direction of a method or formula, they have worked themselves up so much they quite often forget the methods or formulae.

This prompted the design and development of a visual aid (Numeracy Mats) that aims to model self-questioning as a metacognitive approach for problem solving whilst improving memory recall.

Design Process

Numeracy Mats

Aesthetics for memory recall

Since aesthetics of resources in the learning environment can improve performance (Fisher, Godwon & Seltman, 2014), considering the visual aspect of the mats was an important element of the design process, particularly the colour and font that might promote the greatest memory recall.

Disfluency as a result of 'desirable difficulties' (aspects of a resource or task that provide the optimum level of cognitive burden, purposefully implemented to discourage the passive consumption of information) (Diemand-Yauman, Oppenheimer & Vaughan, 2010, p.1) has been found to positively influence the recall of learnt information as it leads learners to process information more deeply and act as a cue when they may not have mastery over material (Alter & Oppenheimer, 2009). An approach to eliciting disfluency shown to have such impact (including with high school students in a natural environment) is simply changing the font of presented material to those that are harder to read (Diemand-Yauman et al., 2010). In their study of this, the conclusion was drawn that superficial changes to learning materials can yield significant improvements in outcomes, and since I plan to introduce additional material in the form of the mats to support metacognition and memory, I have strong reason to believe that if something as simple as a change in font can make a difference I should plan for this accordingly. The font I chose to use for the mats was not one readily available on generic word processing software. I instead downloaded and used a font from www.dafont.com that I believed would be attractive to the pupils and create the optimum disfluency.

Colours used for text on the mats was also an important consideration in the design process as literature states it can be influential in memory recall acting as environmental stimuli by both evoking emotional arousal (Dzulkifli & Mustafar, 2013) and attracting attention (Pan, 2012). The latter is fostered by high levels of contrast, such as white on a red background (Hall and Hanna, 2003), yet the use of a white background with black foreground has shown to specifically have better results for short and long-term memory retention (McConnohie, 1999). In addition, emotional arousal plays an essential role in keeping the information in the memory system (Dzulkifli and Mustafar, 2013), although some types of emotional arousal have a greater effect than others. For instance, green is associated with calmness, happiness and comfort (Kaya and Epps, 2004) and red attached with stronger emotions or feelings (Jackson, Linden & Raymond, 2009). The mats were therefore designed with a white background, self-questions in black and a combination of methods/formulae in red and green.

Theoretical evidence for presented information

With regards to the information presented on the mats, I chose to focus solely on the Numeracy content of the GCSE qualification mainly for the reasons mentioned in the first section. I limited myself to the Numeracy syllabus in order to focus on the problem and for the purpose of the design, which was an extensive task. This came to light more so during the design process even without the extra content required for the Mathematics syllabus. In fact, during this time the decision was made to narrow this down further to the Number and Geometry domains only as the design time had begun to overrun considerably and it was important to me in the interest of my pupils to start making an impact with the mats as soon as possible. I used the new WJEC Guidance for Teachers (Mathematics, Mathematics – Numeracy) (WJEC, 2015) to inform this information but also my own experience to include other information which I believe to be easily forgotten or dismissed as useful.

The format of presenting the information on the mats is based on the theoretical perspective of metacognition and its influence on problem solving. Metacognition is active mental participation (Flavell, 1979) and has been defined as "actively attending to one's thinking" (Pate & Miller, 2011, p.73). Swanson (1990) suggested that when engaged in problem solving, pupils only have partial knowledge about a problem and its solution. This therefore creates a scenario where the student initiates a general search for information and possible solutions. It is this search that is guided by pupils' metacognition.

However, pupils often experience problems with regards to their metacognition, in the form of givens, obstacles and goal state (Anderson, 1985). Givens are limitations and characteristics that define the initial state of the problem and obstacles are known and unknown givens that make it difficult to reach the desired outcome. In my experience with my study group, a major obstacle has been the inability to make connections with required methods and poor memory recall of formulae/methods/iterative processes.

There is an abundance of literature in how to train pupils in their metacognitive skills and how to access metacognitive strategies. However, I truly felt that with my specific class and pupils, whom I had tried these things with in the past, their issue with accessing Numeracy style questions was the inability to make connections between the problem posed and the methods or skills associated, which they then had trouble recalling. Furthermore, I agree with Glaser (1984) who argued that general metacognitive problem solving strategies have little benefit for teaching specific skill sets and that general problem solving methods are less powerful because of a lack of domain specificity. Therefore, I would argue that my pupils' difficulties in problem solving are rather due to the inadequacies of their knowledge in how to access metacognitive strategies in domain specific situations rather than their levels of literacy or ability to use generic problem solving strategies. However, explicitly teaching metacognitive strategies within content-driven lessons can create competition within cognitive capacities such as memory and attention. As argued by Perkins, Simmons and Tishman (1990), adding metacognitive strategy during instruction of domain specific information, may disrupt performance due to cognitive overload. Therefore, explicit metacognitive training could be detrimental to pupils acquiring the content knowledge deeply, which will ultimately lead to a decrease in the ability to solve problems anyway. This is why I have created the mats so they can be accessed in every Mathematics lesson (stuck to all tables using self-adhesive plastic) and used within normal lessons, as well as placing a large emphasis on the awareness of memory recall.

Ozsoy and Ataman (2009) identified self-questioning as a strategy for developing metacognition within the framework of constructivist learning. Self-questioning can include teacher-generated questions or student-generated questions. My follow-up study is built around the idea that if I can provide my pupils with explicit instruction and self-questioning prompts, they will gradually learn to generate their own questions through systematic instruction and use the skill independently. I hope that by presenting my pupils with questions they will ask themselves about what is being read and subsequently become active with the long, wordy problems. Furthermore I hope it will encourage them to think about what they are reading and gain the skills to effectively reflect on what they read.

Metacognitive Awareness in Maths Inventory

In order to help measure the success of the mats, I then designed a questionnaire (for pre and post) named Metacognitive Awareness in Maths Inventory (MAMI) (Appendix B). This questionnaire has derived from the Metacognitive Awareness Inventory (MAI) (Schraw & Dennison, 1994), the Metacognitive Awareness Inventory Junior Adaption (Version B) (MAI-Jr) (Sperling, Howard, Miller & Murphy, 2002) and the Questionnaire about Learning in Mathematics (QLM) (Peklaj & Vodopivec, 1998). It is a 31 item, likert-scale (ranging from 1 (never) to 5 (always)) questionnaire that I piloted with my form class (not part of the study group).

The reason for not using solely the MAI or MAI-Jr was that the first was designed for use with university students, and the latter, although wording of questions was much more accessible, was designed for Key Stage 2-3 pupils. In addition to this, neither were Mathematics specific, so I adapted some questions to make them so. The QLM added an additional dimension to the questionnaire as it also included some metacognitive consciousness and affective processing questions and these were Mathematics specific. I used SPSS to carry out a test of reliability and it performed very well, with Cronbach's alpha 0.82. My study group have provided answers to the questionnaire and I have collected this data and calculated means. The purpose of the Metacognitive Awareness Inventory (Schraw and Dennison, 1994), is to both evaluate learners' needs for possible metacognitive strategy intervention and/or as a tool to measure the effectiveness of ongoing interventions. The latter is the main purpose for the design and administration of the specially designed Awareness in Maths Inventory.

Conclusion

Once complete, the mats were printed across six a3 pages and stuck to every table in the classroom using clear self-adhesive plastic. Prior to this, the MAMI was administered along with a numeracy test made up of past paper questions. These will be compared with post-questionnaire results and post-numeracy test results and along with academic data will be used as measures of the mats' success. The use of the mats were modelled and the pupils have since been using them in lessons and in examination preparation when tackling numeracy problems. This will continue in the new academic year in the lead up to the group's GCSE examinations and the success of the mats will be reported on in Autumn 2018. The mats have not only received a positive response from the group for which they were designed, but other classes including lower ability or younger groups who aspire to use the mathematics presented on them. The mats have also caught the attention of members of staff, who have asked to have duplicate versions for maths classrooms, but also enquired into the design process with the consideration of designing something similar for their subject.

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