2016 cohort

Dave Farmer – Physics Teacher

Can we improve student's performance in physics by learning from maths?

This project looks at an intervention designed to improve student confidence and attainment when answering algebra based questions as part of their physics GCSE content. Exam analysis from the most recent GCSE's showed that our students perform below the national average on algebra based questions, particularly in the foundation tier. Analysis of student work often shows that when questions are attempted, little evidence of working out is seen, or the working out is not structured or clear. This chimes with teachers' observations that students routinely struggle with calculation questions, often resorting to combining numbers at random. Many students will give up before even attempting. The students themselves often report low confidence tackling problems. They often say they "don't know where to start" and even students who say they are good at maths will report that they don't "get it" in physics lessons. As these questions make up a significant percentage of the marks available on the Physics GCSE, there is clearly a need to tackle this issue.

Algebra questions in maths and physics fit in to the domain of 'well-structured' problems in cognitive science (Nelson, 2017), and there has been much work on modelling how our brains approach problems such as these. Simply, we rely on two types of memory: long-term memory (LTM), where elements of knowledge are stored and working memory (WM) where elements are processed, for example recalling a relationship from LTM or calculating a maths result. WM has an essentially unlimited ability to recall elements that are suitably activated from LTM (Kirschner et al., 2006). Elements entering WM that cannot easily be retrieved from LTM are termed 'novel' and WM only has a limited capacity to deal with these. For adults it is estimated that only 3 to 5 novel elements can be held and processed in WM at each step of problem solving (Cowan, 2010). It is clear that this may well have a limiting effect on students' ability to process and solve calculation questions that typically involve many steps.

I order to find a way to overcome the limits of working memory there are many steps that can be taken. Chunking a problem helps but is a skill that requires a level of expertise to begin with (Willingham, 2006). For many maths concepts, algorithms can be used in order to develop a procedural understanding that supports understanding of the concept (Wu, 1999). In the same way, providing an algorithm or procedure for a more complex task can help 'overcome the bottleneck' of WM by assisting with chunking the problem or by removing the process of deciding where to start or what to do next from WM (Willingham, 2004).

As the desired outcome is for a student to build a level of automaticity towards the problems, it makes sense to explore where else these skills are taught in this context and to mimic existing procedures if they exist. To this end, conversations were carried out with the school maths

department to unpick their procedures and explore common student issues. The following themes emerged:

- The students prefer having a set method they can follow for a particular type of problem.
- The students find it easier to manipulate equations after substituting numbers in.
- The language used to describe the same process in mathematics may be different to that commonly used in physics e.g. change the subject vs rearrange.

The intervention being tested is the effect of introducing an explicit procedure (algorithm) for completing 'calculate' questions in Physics. The procedure was designed in collaboration with the Maths Lead Practitioner at the school in order to be consistent with the way the skills are taught in maths:

1. Pick out the variables
2. Check for unit conversions
3. Choose and write your equation
4. Substitute numbers in
5. Tidy the equation
6. Solve for [unknown]

The intervention will be completed with 2 Year 10 classes during their Forces and Motion unit. They have been chosen because at this age the pupils have started GCSE content where they will be expected to complete algebraic questions more regularly in their physics lessons. The students will be introduced to the method at the start of the unit and it will be repeatedly and explicitly flagged and returned to throughout the unit whenever algebra questions are involved.

In order to investigate the impact of the intervention the following data will be collected:

Data	Collection Method	Analysis
Pupils' self-reported confidence.	Baseline/Final questionnaires	Comparison between average values on baseline/final questionnaires.
Pupils' reported feedback on method.	Baseline/Final pupil interviews	Analysis of pupils' statements regarding confidence in algebra questions e.g. strength of language used to describe their ability at algebra questions.
Pupils' performance on algebra tasks.	Baseline/Final algebra task	Evidence of use of intervention method on baseline vs final test. Completion rate. Average score.

Questionnaires have been selected for this task as they provide a quick way to survey a reasonable number of pupils in a sensible time scale. Care has been taken to make sure that the questions being asked are well defined and the questionnaire has been kept deliberately short to combat any possible question fatigue (Denscombe 2017). Scaling questions have been chosen as they are ideal for trying to assess a strength of feeling towards a particular statement - in this case linked to confidence (Bell 2010). The limitations of these questionnaires lies in the variability of the pupils and in the accuracy of their reporting. The responses are likely to be somewhat subjective. This is mitigated slightly by using two classes of responses (~60 pupils) and comparing average values but will ultimately limit the strength of the conclusions that can be drawn from them.

The questionnaires will be supplemented by the pupil interviews. These should provide a chance for more qualitative feedback from a group of pupils and should help start to illuminate or unpick the reasons behind any observed impact. Again, the strength of the conclusions that can be drawn from these will be somewhat limited due to the small number of interviews and the relatively open format but they should help build a picture of the impact along with the questionnaire responses.

The final piece of data being considered is pupil responses to an algebra task. While it may be possible to draw some conclusions from the average attainment before and after on the task it is expected that the attainment would increase across the unit as pupil got more familiar with the content regardless of the method used. This means it will be hard to draw conclusions as to what impact the intervention has on attainment. Instead, the task can be used to scrutinise pupils' working methods and will act as a indication of how well embedded the intervention method is. If the pupils report increased confidence but there is no indication of the taught method being used then it will serve to balance any conclusions made about the efficacy of the intervention. It should be noted that the reverse is not necessarily true and that evidence of using the method will not alone be evidence of the efficacy of the intervention without being backed up by feedback from pupil interviews and final questionnaire.

Initial findings from the project support the claim that pupils have low confidence towards algebra based problems. The baseline questionnaires show that students on average rated their confidence in physics much lower than in maths. Additionally, on average, pupils suggested they rarely knew how to approach algebra based questions and had low confidence in getting them right. The interviews conducted supported these results and even where pupils said they knew what to do with a question they were unable to articulate this.

The baseline algebra tasks showed a wide range in methods being used by the pupils. Many left questions unanswered or appeared to have combined numbers at random as previously observed in assessments.

The intervention has been taking place in lessons and early observations are that it is being successful in lowering the entry point for pupils with algebra questions and as they are more likely to successfully complete them their confidence appears to be increasing as a result. It remains to be seen whether the intervention method has been embedded strongly enough for pupils to use it during assessment conditions, and whether they report an increase in confidence on the final questionnaire.

While it is too early to say whether there is a lasting impact on pupil confidence and attainment as a result of making the problem solving method explicit to them, early indications appear favourable. In addition, the process of collaborating with the maths department on designing the method has proved invaluable – not just with the pupils involved in the intervention but with all classes being taught. Simple changes in language and pedagogical changes such as substituting numbers before attempting to change the subject of an equation appear to be simplifying maths problems in physics for pupils. It has also opened up the possibility for a deeper collaboration where, for example, the maths department could use physics problems to practice key skills – certainly a route to be explore in the future.

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