

The response of the National Network for Excellence in Mathematics (NNEM) to the Welsh Government on improving mathematics education in Wales in view of PISA findings.

Background

The Programme for International Student Assessment (PISA) is a worldwide study by the Organisation for Economic Co-operation and Development (OECD) in member and non-member nations of 15-year-old school pupils' scholastic performance on mathematics, science, and reading. PISA has great significance in the development of Welsh education policy and, in view of the recent reforms of assessment and content of GCSE examinations in England and Wales, PISA results are likely to become the only major baseline comparison for Welsh education system not just internationally but also within the UK.

In June 2017 the Welsh Government approached NNEM about advice on how the information from the PISA 2012 and 2015 results could be applied to the work of NNEM and more general advice on furthering mathematics teaching and learning nationally in response to the PISA findings. The main PISA findings in the context of these paper include Wales and global reports and additional analysis undertaken on the Wales results (additional analysis for the 2015 results is underway and will be shared with the NNEM in the coming months), alongside further research undertaken by the OECD on mathematics pedagogy and approaches (OECD, 2014; Wheeler et al, 2013; Jerrim and Shure, 2016; and OECD, 2016a and 2016b). Both NNEM and the Welsh Government agree that the advice should be on how mathematics practitioners can be supported to ensure students are being stretched year on year resulting in higher achievement in mathematics by Year 11.

The proposed question is important for NNEM and links with a number of priority areas set out in the NNEM high level plan and, in particular, with the work of the NNEM pedagogy group which aims to initiate evidence based pedagogical developments in mathematics teaching build on understanding of what constitutes effective practice as well as to develop teacher professional learning programmes to underpin this. As well as the documents above, a number of research documents have been considered to ensure that our advice is underpinned by robust evidence. We also believe that Welsh context is vital and thus whenever possible we looked at the evidence of the Wales specific research projects in this respect. While PISA makes a great emphasis on applying mathematics to problem solving and decision making which is vital for the development of children living in the 21st century, the view of NNEM is that mathematics should not be restricted by the content of PISA questions. However, we agree that OECD documents make recommendations to teaching of all three kinds of mathematics (factual recall and following algorithmic procedures, applying known mathematics in new situations and application of conceptual knowledge to construct mathematical arguments, see, e.g., Smith et al 1996 or Darlington, 2013 for an explanation of the classification) and thus we were looking to touch on all of the above in our recommendations.

In July 2017, the NNEM work began with a group discussion of three key questions:

- How can the information (from PISA related reports) be applied to the work of the NNEM and new approaches to teaching and learning?
- What advice the NNEM might give to Welsh Government to consider more widely in taking forward mathematics?
- How could the NNEM support teachers in providing greater stretch year on year?

The paper is organised as follows. PISA findings and related reports are summarised in Section 1. The main discussion points from NNEM meetings on 14th July and 4th October, 2017 and are outlined in Section 2. We then suggest action for NNEM and recommendations for the Welsh Government that have resulted from discussions (Section 3). This includes a few areas where further research into Welsh practices to build on existing success and eliminate problems may need to be undertaken. The paper concludes with a short summary and a list of references.

We do not consider the response produced in this paper as final but rather see this work as ongoing development as part of establishing NNEM in Wales.

Section 1: PISA results in mathematics and the teaching and learning implications

1.1 An overview of mathematics performance by 15-year-olds in Wales (2006-2015)

There has been a decline in results and although the decline itself is not significant (in comparative terms), it shows that there has been no improvement in the mathematics scores in the last decade, see the table below. PISA mathematics scores in Wales are below those of England, Scotland and Northern Ireland and, as Jerrim and Shure (2016) point out, countries including Italy, Portugal and Russia have either caught up or overtaken Wales. For reference, the mean score for mathematics since 2006 are shown below:

Year	2006	2009	2012	2015
Mean score for Mathematics in Wales	484	472	468	478

Particularly significant is the comparative performance of the highest and lowest achievers in Wales. The 2015 results revealed that Wales has a smaller proportion of high achieving pupils in mathematics (5%) than average across other OECD members (11%). Furthermore, the highest achieving pupils in Wales perform significantly below the highest achievers in top performing countries. The top performing 10% of 15-year-olds in Wales in 2015 scored 578 or more. This is significantly below the top performing 10% in Singapore (where those pupils scored 682 or more). Furthermore, there are 36 countries where the 90th percentile is more than 20 points above that for Wales. As Jerrim and Shure (2016) point out, only three industrialised OECD members (Turkey, Mexico and Chile) have their 90th percentile scores lower than Wales.

The lowest achievers in Wales (in the 10th percentile) also perform comparatively worse than other countries although this difference is not as pronounced. There are ten countries whose lowest achievers perform comparatively better than the lowest achievers in Wales (five within East Asia but also of note are Ireland and Canada).

Hence although the gap between the highest achieving and lowest achieving pupils is smaller in Wales than in most other countries, one of the reasons for this gap is that there is a lack of pupils with high-level mathematics skills.

The performance of boys and girls in the 2015 mathematics tests also highlights a comparatively pronounced gap (boys achieving a mean score of 483 and girls a mean score of 473). This was similar to results in 2009. Of note is that such differences are not typically reflected in GCSE results, although there is a suggestion that similar results may be reflected in the new GCSE Mathematics: Numeracy (it should be noted, however, that early entry may affect such data).

The 2012 cycle of PISA assessment incorporated a more detailed focus on mathematics and therefore analysis of this data provides further information about specific aspects mathematics learning in Wales. Headlines from this analysis (Wheater *et al*, 2013) are that:

- Pupils were relatively strong on questions that focus on probability and statistics
- Pupils were relatively strong on questions that require them to interpret, apply and evaluate mathematical outcomes to solve problems
- Pupils were less strong on questions that focus on space and shape
- Pupils were less strong on questions that require them to formulate situations mathematically
- Analysis of results considering socio-economic backgrounds suggests the gap between the performance of the most advantaged and disadvantaged pupils is relatively low in Wales
- Pupils were, on average, not particularly interested in learning mathematics but did show instrumental motivation to learn it (recognising that it is useful)
- Pupils were either below or in line with OECD averages when reporting openness to problem solving
- Pupils were either below or in line with OECD averages when reporting involvement in mathematics outside school
- Pupils were generally higher than OECD average when reporting their experiences of teaching being inclusive and supportive
- Pupils were higher than OECD average when reporting experiences of 'Cognitive Activation' strategies (e.g. reflection on problems, tasks that require extended thinking, learning from mistakes)

Analysis of the responses to PISA mathematics questions in 2015 is nearly complete and will be published shortly. This analysis suggests similar findings to results in 2012. A particular weakness of learners in Wales, identified by this analysis, is the ability to formulate situations mathematically. Application of mathematical concepts, facts, procedures and reasoning is also a weakness, although not as pronounced as the ability to formulate.

1.2. Overview of PISA informed reports into mathematics learning and teaching

Analysis of PISA results and OECD country practices provide an evidence base in mathematics learning and teaching and have been used in reports contributing to the literature on effective pedagogy in mathematics. Three such reports are: 'PISA in Practice: Cognitive Activation in Mathematics' (Burge et al, 2015), 'Ten Questions for Mathematics Teachers' (OECD, 2016b) and 'Equations and Inequalities: Making Mathematics Accessible to All' (OECD, 2016a). A summary of key themes from these reports is given in this section.

Cognitive Activation (CA) is a term used to describe pedagogic choices which encourage learners to think deeply and make connections. It includes practices such as:

- Encouraging pupils to reflect on problems
- Giving pupils mathematics problems that require thinking for an extended amount of time
- Asking pupils to use their own procedures for solving complex problems
- Creating a community where pupils are able to learn from mistakes
- Giving pupils problems with no immediately obvious method of solution or with multiple solutions

- Presenting pupils with problems in different contexts and asking them to apply their learning to a new context
- Asking pupils to explain how they solved a problem and why they chose that method

PISA questionnaires within a mathematics focused cycle of PISA assessment (such as in 2012) ask pupils to report on their experiences of these CA practices. Analysis of results of the questionnaires alongside analysis of PISA mathematics performance suggests that CA practice is associated with higher mathematics achievement. Furthermore, CA practice seems to particularly benefit pupils with low and medium socio-economic status (SES). A further benefit of CA is that it relates positively to characteristics such as motivation and self-efficacy. Such claims by Burge *et al* (2015) would not be considered new in the mathematics education field; for many years researchers have made similar claims. For example, Boaler (1998 and 2016) argues that practices such as engaging pupils in extended problems, asking them to use and discuss their own procedures, giving problems with no immediately obvious solution and creating an atmosphere in which mistakes are seen as opportunities for learning will impact positively not only on attainment but also on mindset. Moreover, these practices are recognised as those that benefit girls (but also boys) who have a lower self-concept (Mendick 2005b).

In the CA report, Burge *et al* (2015), through analysis of PISA results in England in 2012, claim that low achieving pupils report lower experience of CA strategies than higher achieving pupils. This may be because teachers feel that lower achieving pupils are less able and, hence, they choose less cognitively challenging tasks for them. However, Burge *et al* (2015) also point out that although the association between exposure to CA strategies and higher mathematics achievement is significant across all pupils, it cannot be claimed to be a causal relationship. Burge *et al* (2015) also claim that CA is linked positively to intrinsic motivation in mathematics and instrumental motivation. Again, the cause of the relationship is not clear.

More complex is the relationship between CA and self-belief in mathematics skills. For pupils with low SES, although there is a positive relationship between the use of CA strategies and self-efficacy and self-concept, it appears there is no positive relationship between the use of CA strategies and mathematics anxiety. Hence a higher level of CA strategies is not accompanied with a lower level of mathematics anxiety in low SES pupils. As PISA results internationally (such as those in 2012) show a relationship between SES and mathematics achievement, this suggests teachers need to be particularly mindful of choice of teaching strategies for pupils with low SES.

The OECD (2016) report 'Ten Questions for Mathematics Teachers' supports and reinforces Burge *et al*'s (2015) claims. This report uses data from 2012 and from the 2013 Teaching and Learning International Survey (TALIS) to identify key teaching and learning strategies for mathematics teachers. In many respects the conclusions of the report are unsurprising. For example, the report recognises there is complex relationship between achievement and the balance between teacher and student directed 'active' learning. There seems to be a positive relationship between direct student learning and success in simple problems but as problems become more difficult, the effect of direct instruction is lessened. Also unsurprising is that there is a relationship between teacher self-efficacy and the use of more active learning

strategies (the higher the teacher's self-efficacy, the more likely the use of active learning strategies). Furthermore, the greater the collaboration between teachers within a school, the more likely the use of CA strategies. The report also recognises the importance of a positive and supportive classroom environment and the need for balance between coverage of core concepts (and reinforcing connection between these) and a variety of applied problems to solve. Furthermore, when discussing the teaching of problem solving, the report suggests the importance of using problem solving as a teaching approach rather than as an application of skills already learned.

Similar points to those discussed above are raised and explored further by the OECD (2016) report 'Equations and Inequalities', which focuses on how education systems can make mathematics accessible to all learners, with a particular focus on learners with lower attainment and/or low SES. Conclusions from this extensive report are particularly useful for policy makers. They include consideration that teachers need support in developing pedagogies such as flexible grouping and co-operative learning, which are recognised to increase learning opportunities for all pupils. Furthermore, the report recognises the need for the use of 'well-designed, challenging problems' (OECD, 2016: 14) to extend higher-order thinking skills. It also continually emphasises the importance of teacher support; through teaching materials and training.

To summarise, key points raised from PISA mathematics results have been:

- The importance of balance and connection in the teaching of core concepts
- The importance of regular exposure to practices that develop higher order thinking
- The relationship between Cognitive Activation strategies and achievement
- The relationship between the use of Cognitive Activation strategies and self-efficacy
- The importance of collaboration between teachers, training and the role of support materials

And the key points for Wales, in particular:

- The need to raise achievement of all learners in mathematics and, in particular, the level of higher achievers in mathematics
- The need to support learners in applying their mathematical understanding and reasoning, and in formulating mathematical situations
- A focus on the attainment of girls in mathematical literacy (see also Tanner and Jones, 2013)

Section 2: Points raised through NNEM discussion

Key themes that arose from group discussions, and those that the NNEM pedagogy group should consider are summarised below. It should be noted that some points raised may be beyond the remit of the NNEM (e.g. the impact of GCSE examinations on practice) and some (e.g. curriculum content) are being considered by the Mathematics and Numeracy pioneer curriculum development group. However, as these are interlinked with approaches to teaching and learning we included them in the discussion below.

Reasoning, problem solving and depth of understanding

All groups made reference to the importance of reasoning and problem-solving as a way of ensuring depth of understanding and for ensuring challenge with higher achieving learners. The practice of accelerating higher achieving learners through content was also discussed, and this also related to comments about transition and setting, see below. A few references were made to the Mastery approach, which involves ensuring depth of understanding through increasingly complex problems and tasks. It was suggested that the impact of this approach should be researched and, in particular, schools in Wales that have adapted this approach should be consulted. Whether or not the term Mastery is used, the importance of developing teachers' understanding of approaches to developing reasoning and problem solving in mathematics (including statistics) and numeracy was recognised as a key priority by all groups.

Attitudes towards mathematics

Several groups raised the importance of promoting the idea that mathematics is complex, 'messy', and a challenge which has been discussed previously by the NNEM. More work is needed to change attitudes towards mathematics and beliefs about mathematics in the Welsh society. Although this point may link to the communications group work, it could be linked to the activity of the pedagogy group through promotion of that message as an aspect of effective pedagogy.

Learner self-regulation as part of learning mathematics

Research evidence strongly suggests that a self-regulating learning process is crucial for academic success. Zimmerman and Pons (1986) remarked that success in school, particularly in higher grades and in unstructured settings, is believed to be highly dependent on student self-regulation. Moreover, self-regulation can be a better predictor of achievement than gender or socioeconomic metrics. While there are examples in Wales where becoming self-regulated learners is an organic part of teaching mathematics, this is not seen as part of teacher professional development. Yet, it is all the more relevant to the undergoing school reform in Wales (Donaldson, 2015). One component of self-regulation associated with self-efficacy is "persistence of motive and effort" (Cox, 1976). This should help students to develop resilience, which, in turn, should help students overcoming anxieties associated with problem solving and PISA style questions.

Professional development for mathematics teachers who come from non-mathematics specialists backgrounds (e.g., accountancy, engineering etc)

The pedagogy group needs to consider the professional learning pathways for non-mathematics specialists in secondary sectors. It also needs to consider mathematics

professional learning pathways for primary practitioners. There is evidence that lower mathematical confidence of teachers may transfer into low confidence of their students (McLeod, 1992; Beilock et al, 2010; Hill, 2016).

Gender differences and good practices

Research findings suggest that the problem of girls under participating and/or underachieving in mathematics should not be treated as a separate problem. Rather, gender misbalances may indicate underlying problems in the approaches to teaching mathematics that disadvantage both girls and boys and good practices in teaching mathematics are known to benefit both genders (Smith 2010 and 2014; Smith and Golding, 2015; Mendick 2005a and 2005b). International research on affect in mathematics states that there is evidence that girls have a lower than boys mathematics self-concept but at the same time are likely to attribute their success to effort rather than luck or ability (McLeod, 1992; Hendley et al 1995). Thus looking at existing good practices in girls' achievement in PISA and Numeracy GCSE exam should be treated as a priority. These examples may reveal key approaches that benefit all students and will probably indicate a good whole school approach to learning in general and in both students and teachers (Cann, 2009).

Using the NNEM and, in particular, the NNEM Hwbzone as a platform for sharing effective pedagogic practice

The groups were concerned with finding effective ways of communicating good practices and sharing findings. Written materials remain a good source of learning for teachers but short videos should be created whenever possible. Groups commented on ensuring the NNEM is used to share effective practice. The use of the Hwb zone for sharing video materials (e.g. short clips relating to extending higher achievers/lessons promoting reasoning) and also support materials (e.g. examples of tasks that would demonstrate how depth of understanding rather than breadth could be developed) was raised.

Mathematics Curriculum Content, Transition (from primary to secondary to post-16 and to HE) and 3-18 schools

We grouped these themes together as we felt that they are beyond immediate remit of NNEM while still being important.

- While mathematics is embedded in every subject, we felt that a clearer emphasis is needed to spread this message and showcase good practices of mathematics being used in various subjects, such as pie-charts in History. This at the same time could also help to re-enforce the message that mathematics is for everyone and a key component of many subjects.
- Transition at every stage of a child's journey through education is important to look at. There is common understanding that the transition from primary to secondary is easier when students study in 3-18 schools. As a number of new 3-18 schools increase in Wales, this may create opportunities for researching into effective practices. A reference was made to independent schools that often have a mathematics specialist in primary as well as in secondary phase of the schooling. There are known examples where secondary teachers spend some time teaching in primary feeder schools or run

extra curriculum mathematics activities with children to aid their transition (Ri mathematics master classes for primary for example). Equally primary teachers may benefit from spending some time in secondary classrooms.

- Studying additional mathematics Level 2 qualifications is known to aid transition from GCSE to A-level (Tanner et al, 2016) while Further Mathematics is recognised to help the transition from school to university mathematics (Lyakhova and Neate, 2017). However, shortcomings of both A-level qualifications associated with the contrasts in the pedagogies and assessment practices of post-16 mathematics qualifications and undergraduate courses have also been noted (Darlington, 2014; Lyakhova and Neate, 2017). Mathematics exams at GCSE and A-level across various exam boards test mostly factual recall and procedures. The Numeracy paper is a welcome addition as it tests applying mathematics in new contexts, although mathematical reasoning to construct mathematics arguments is not available anywhere in the syllabus at either GCSE or A-level.
- OECD strongly recommends that setting and streaming is delayed as much as possible. However, we felt that practitioners would need a lot of support to trial such an approach and thus if we decide to research into this it would be a longitudinal study.
- Change in pedagogical practices should help to improve learners' outcomes at all levels, including stretching high achieving students further. However, we felt that in short term programmes such as SEREN and Aspire should be able to help. There is a variety of outreach programmes in mathematics available across Wales, however, the impact of outreach is rather difficult to evaluate.
- While the recent Smith review of post-16 mathematics pathways in England (Smith, 2017) stated that there was no case at present for mathematics becoming compulsory till the age of 18 in England, the report stressed the importance of alternative qualifications such as Core Maths being available. The report said that 32% of those who achieved A*/A at GCSE Mathematics in 2015/16 in England and did not take A-level Mathematics, studied A-level Biology, followed by History (28%), Psychology (27%) and Chemistry (20%). One may argue that all these subjects would benefit from being underpinned by studying more mathematics. Core Maths refers to a set of qualifications designed to provide opportunities for students who achieved at least GCSE grade C in Mathematics but are not taking A-level mathematics. The numbers of students taking the new qualification are currently small (there were only 3000 entries in 2016/17 in the UK). It is difficult to disagree with the fact that giving more students an opportunity to pursue mathematics further contributes to Four Purposes of the new curriculum in Wales. One aspect of 'becoming ambitious, capable learners ready to learn throughout their lives' as presented by Mathematics and Numeracy AoLE representative at the NNEM meeting on 4th October 2017 was identified as "developing a lifelong interest in mathematics". If we stress the importance of learning mathematics till 16, we ought to be consistent in promoting it for post-16 as well.

Section 3: Implications and recommendations

Following the discussions, the following actions are recommended to be taken forward by the NNEM pedagogy group.

Action	How	When	Success criteria
To audit the professional learning pathways for primary and secondary non-specialist teacher (possibly include all PL courses) across Wales	Collect info about all PL opportunities available in each consortia and nationally and provide a comparison. Identify the gaps and collect info on what is available across UK to overcome the gaps in teaching skills and knowledge. Consider the role of technology.	June 2018	Clear overview of PL landscape in Wales with gaps identified and proposed new courses to fill these gaps
Prepare a research plan for a longitudinal study on where good practice is in Wales and what are the most effective ways of encouraging teachers to advance their practice in the context of Wales	NNEM Research coordinator to work with the pedagogy group on developing a plan.	July 2018	A comprehensive plan including a timeline for deliverables, agreed strategy for evaluation and funding required.
Linking 2017/18 Action Research projects with the themes identified in this paper	NNEM Research Coordinator to review research themes and identified possible areas of interest	Jan 2018	AR project either completed or making substantial progress by July 2018

Items identified for further discussion for the NNEM pedagogy group include:

- Stretching high achieving students. A proposed approach focused, so far, on universities offering a series of master classes to schools who need extra support. A possible criteria for identifying these settings included PISA and GCSE Numeracy results.
- Developing a NNEM communication plan which targets a wider audience.
- To promote and exemplify the development of reasoning and problem solving as key features of effective pedagogy.
- Consideration of international effective practice in mathematics through a field trip. China, New Zealand, France and Finland have being mentioned as countries with various areas of strength in their approaches to teaching and learning mathematics.

The view of NNEM is that we see professional learning of teachers as the key to changing practices in Wales. It is recognised that there is already work actioned by the Welsh Government to establish a national approach to professional learning, as outlined in the 'Education in Wales: Our national mission action plan' (Welsh Government, 2017). The

approach of NNEM is the one based on three strands: **research evidence** gathered from education research across the world, tested **in Wales** and good practice **shared with the whole community of Welsh practitioners**. While we propose to research existing practices, we do not expect to uncover new revolutionary methods. Rather, we shall find that some of the well-known and well-recognised pedagogical practices have already been tested in Wales and some practices are better suited than others. We also expect to find a variety of approaches that work depending on socio-economic status and other parameters of a school setting. Schools may or may not be aware what makes their approach work, but working alongside an experienced mathematics education researcher should help to make findings more comprehensive. It is important that the sample of schools chosen to participate in research projects is representative to Wales and is a stratified sample. Comparing practices research evidence should help us to further identify pedagogical principles that underpin good practices that work in Wales and progress on to building more consistent and coherent professional learning programme across Wales. The research findings should inform professional learning courses. In longer term, we would like to see Welsh mathematics practitioners turning into scholars who research into one's own practice.

Finally, we would like to make a few remarks on some of the items discussed that are beyond immediate remit of NNEM.

Assessment practices, and the content of examination and national numeracy tests papers in particular, are seen as those that continue influencing teaching in the classroom. We feel that it would be beneficial to continue encouraging revising the content of the examination and national test papers as well the whole approach to assessment. Qualification Wales, NNEM and WJEC should be encouraged to work together to update each other on their views, findings and progress.

Both subject-specific and pedagogy-specific national professional learning programmes (and, ideally, a comprehensive blend of both) should be established in Wales in long term. These components are equally important in teacher training programmes in Wales. Any long-term reform of teacher training should attempt to strengthen and ensure consistency of both.

More generally, NNEM feel that an attempt to adopt one or other "fashionable" approaches, such as Mastery or Shanghai, is too narrow. At all times, the emphasis should be made on there is a variety of approaches that work well, but adapting these may depend on many factors, as well as individual circumstances of educational settings.

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