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European Music Portfolio (EMP) – Maths: Sounding Ways Into Mathematics

A Review of Literature

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Lifelong Learning Programme

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Learning to be a mathematician

Caroline Hilton

'Mathematics' and 'mathematical thinking'

What is 'mathematics? It has been very hard to find a satisfactory definition of 'mathematics', not least because mathematics is continually growing and changing. From a child's perspective, mathematics should be creative, inspiring and full of wonder. Jo Boaler cites a lovely quotation from Margaret Wertheim:[1]

> When I was ten years old I had what I can only describe as a mystical experience. It came during a math class. We were learning about circles, and to his eternal credit our teacher, Mr Marshall, let us discover for ourselves the secret image of this unique shape: the number known as pi. Almost everything you want to say about circles can be said in terms of pi, and it seemed to me in my childhood innocence that a great treasure of the universe had just been revealed. Everywhere I looked I saw circles, and at the heart of every one of them was this mysterious number. It was in the shape of the sun and the moon and the earth; in mushrooms, sunflowers, oranges, and pearls; in wheels, clock faces, crockery, and telephone dials. All of these things were united by pi, yet it transcended them all. I was enchanted. It was as if someone had lifted a veil and shown me a glimpse of a marvellous realm beyond the one I experienced with my senses. From that day on I knew I wanted to know more about the mathematical secrets hidden in the world around me.

This extract clearly encapsulates the fact that mathematics is all around us, and once discovered, has fantastic qualities all of its own.

What then is involved in developing mathematics and thinking mathematically? According to Leone Burton, mathematical thinking 'is mathematical not because it is thinking about mathematics, but because the operations on which it relies are mathematical operations'.[2] Citing Hofstadter (1979), Burton goes on to suggest that mathematical thinking relies on pattern recognition, iteration and repetition; processes found not only in mathematics, but also in music and art, for example in the works of Bach and Escher, to name but two. Learning mathematics, according to this definition, would require children to explore mathematical questions and relationships in messy and often haphazard ways, in attempts to make sense of what they find.

Marcus du Sautoy tried to capture the creative nature of mathematics in an interview in the Guardian newspaper:

> I think very often the exciting moments in mathematical history are moments when suddenly there's a leap of imagination - for example, the idea of negative numbers, or zero - I mean, that's almost as imaginary as a four-dimensional

> shape. What's a negative number? I can't show you minus three potatoes - but let's come up with the idea of a negative number and the way that it will behave and explore that. That's why it's a creative subject. It's a lot about creative intuition...in Einstein's view, the ultimate test for an equation was an aesthetic one. The highest praise for a good theory was not that it was correct or that it was exact, simply that it should be beautiful.[3]

A large part of the early mathematics we do with children involves number and arithmetic. The need to count is not instinctive, but is a human creation. The need to compare quantities, however, is a matter of survival.[4]

Number sense

It is not easy to define what we mean by 'number sense'. Tosto *et al*[5] defined 'number sense' as our ability to estimate and work with quantities that are not presented as numerals or symbols (e.g. 2, 5, 379, etc.). We often use our number sense when deciding which is the best queue to join at a supermarket checkout, or which pile of sweets to pick. Using this definition, it could be argued that this is a very useful survival skill and, in terms of human evolution, would precede any need to use numbers for counting exact numerosities.

The issue of 'number sense' has been the subject of a well-known book by Stanislas Dehaene entitled *The Number Sense [How the mind creates mathematics].*[6] In his book, Dehaene explores the possibility that number is a property to which all small children as well as animals have some access. He describes a number of experiments in which researchers have shown that animals, including rats and pigeons, are able to distinguish reliably between the numbers 1, 2 and 3. Rats and chimpanzees appear to be able to add small numbers with accuracy even when the stimuli are mixed—for instance recognising that two flashes and two sounds make 4.

According to Dehaene's[7] research, measuring the length of babies gaze or the rate of sucking has established that they appear to be able to distinguish the numbers 2 and 3 from as early as a few days old in response to auditory or visual stimuli. Babies less than a year old can 'calculate' additions and subtractions within 3 and sometimes up to 4. They are also able match quantities. If faced with two images, one representing 3 objects, when a series of drum beats sounds they will give more attention to the image with two objects when hearing two drum beats and to the image of three objects when hearing 3.

Adults also recognise the quantities 1, 2, and 3 reliably almost all of the time with a significant drop off from 4 upwards (this is called 'subitising'). Dehaene[8] argues that the quantities 1, 2 and 3 are recognised by a neural system specific to these numbers, called the intraparietal sulcus (IPS) (and see the separate section below in this review on neuroscientific evidence). When it comes to larger numbers, adult humans take more time to distinguish between groups that are close in number than groups with a large difference. For instance it is easier to distinguish between a group of 2 and a group of 5 than between a group of 4 and a group of 5. It is also easier for us to distinguish between a group of 1 and a group of 2 than between a group of 4 and a group of 5. This is because the relative difference is greater between 1 and 2 than it is between 4 and 5. Interestingly, this pattern is present not only when looking at groups of objects, but also when looking at the numbers that represent them. Dehaene[9] suggests that human beings somehow use an approximation of the number for comparison rather than relying on an exact knowledge of the relative sizes of quantities represented by each digit. Dehaene[10] also suggests that the increased difficulty in subitising groups beyond 3 is the reason that all written number systems use groups of 1, 2 and 3 marks for the first three numbers and beyond this, rely on more abstract symbols.

Our relative difficulty in distinguishing larger numbers as compared to smaller numbers leads to a suggestion that human beings (and perhaps animals) represent numbers on a logarithmic rather than a linear scale, which would provide a much greater distinction between the numbers 1 and 2 than between the numbers 31 and 32. Such a scale would match with those already established for human perception of continuous measures such as loudness and pitch of sound and the brightness of lights.[11]

Dehaene[12] notes the evidence that there is a strong link between skills in spatial perception and mathematical 'talent'. This, he suggests, may be a logical consequence of the fact that the 'number sense' appears to be located in the inferior parietal area, specifically in the intraparietal sulcus. This area of the brain is also the point at which streams of data from the visual, auditory and tactile senses converge. The intraparietal sulcus appears to be activated by any representation of a number, for example it will respond to the image of the number 3, the word 'three' or an image with three objects. It also activates when considering continuous sensory dimensions such as size, position, angle, time and even light level.

Damage to the inferior parietal area of the brain can lead to a group of symptoms known as Gerstmann's syndrome – acalculia (difficulty with arithmetic calculations), difficulties with representing the fingers of the hand, difficulty in distinguishing left from right and difficulties in writing.[13] This may link to another suggestion that Dehaene[14] makes—that people appear to have a directional feel for number. He suggests that those of us who have learnt to write from left to right tend to associate right with higher numbers, whereas the opposite is true for those from cultures where writing runs from right to left.

According to Dehaene,[15] while the inferior parietal areas on both sides of the brain appear to be involved with understanding the magnitude of numbers, only the left hand side of the brain seems capable of processes that depend on symbolic manipulation of symbols. The right hemisphere can make approximations, however, it is only the left hemisphere can carry out accurate computation. Dehaene[16] suggests that once number facts have been learned (for example, multiplication tables) the intraparietal sulcus may not be used at all. Recall of those facts that have been learned (such as 3 x 3 = 9) rely on verbal recall rather than mathematical processing. The left hemisphere of the brain is better able to manipulate symbols than the right and it seems to be this ability to process symbols that allows it to perform accurate calculation.

Lyons, Ansari and Beilock[17] suggest that mental representations of numbers presented as symbols (numbers or words) are only very loosely linked to actual quantities. The brain concentrates more on the relationship between the symbols than on the quantities they represent and it is these, rather than the quantities themselves, that are being manipulated when we make accurate calculations. Sasanguie *et al.*[18] discovered that the performance of six to eight year old children on mathematical assessments was related to their ability to compare digits rather than their ability to manipulate non-symbolic representations of number (for example, patterns of dots).

Dehaene[19] argues that counting (using exact numerosities) is a social construction. Dehaene[20] reports experiments with tribes in remote areas of the Amazon who have no words for numbers beyond 5. As expected, these people performed very poorly on computing exact answers to calculations, with a rapid drop of accuracy as soon as the limit of 5 was reached. They were, however, able to approximate numbers up to 80 (shown as sets of dots) and compare the sum of two groups shown separately to a third group with an accuracy which came close to that of educated French adults. Dehaene[21] argues that children who have learned to count but not yet learned formal arithmetic, use their 'approximate number system' to decide whether combinations of two digit numbers are more or less than a third number with a success greater than chance would predict. Variation in this 'numerical acuity' has been seen to be a predictor of mathematical achievement, whilst having no relation to reading achievement.

As already illustrated, there is some disagreement in the literature as to whether there is or is not a link between our number sense (or the approximate number system) and symbolic representations of exact numbers using number symbols.[22] Nevertheless, there seems to be a stronger case being made for a correlation between number sense, visuo-spatial skills and mathematical performance across the age range.[23] This has been supported by work done by Tosto *et al*[24] in the field of genetics. Tosto *et al*[25] worked with a group of 16 year old school children. They found that the children's number sense was only modestly associated with genetic factors. Tosto *et al*[26] argue that this suggests that a significant factor in developing number sense is associated with environmental factors, such as home life and school experience. If this is the case, then there is a lot that can be done to support children's development in this area.

As we experience the world around us with all our senses, it is important to consider how our visual-spatial skills support our learning and understanding of mathematics.

Visuo-spatial skills and mathematics

It is known that the intraparietal sulcus supports visuo-spatial working memory.[27] We know that working memory is important for learning, because it is our working memory that allows us to hold information for a short period of time and manipulate it, such as, for example, when trying to add 14 and 107 without using pen and paper, or when remembering a series of instructions to help us find our way to a new place.

Studies in genetics have also explored the link between visuo-spatial skills and mathematical skills. Tosto *et al*[28] used standardised assessments to look at a range of mathematics and visuo-spatial skills. They found that visuo-spatial skills and mathematical skills were moderately heritable, but more significantly, that, in terms of genetics, there was an almost complete overlap between mathematical skills and visuo-spatial skills. They report that this overlap could be explained by environmental factors (40%) and genetic factors (60%). In addition, they found that 'there were no significant genetic effects that were specific to spatial ability once the shared genetic effects with mathematical measures were taken into account'.[29] This suggests that activities which develop children's visuo-spatial skills should also benefit their mathematical skills.

When working with children, the first tools we encourage them to use, to help them count and keep track of their counting, are often their own fingers. Fingers cannot only be seen, felt and moved, but are central to how we, as babies begin to explore and interact with the world around us.

Are fingers important for learning mathematics?

'Whenever a counting technique, worthy of the name, exists at all, finger counting [sic] has been found either to precede it or accompany it'.[30] While this is clearly a well-considered observation, the exact relationship (if indeed a relationship exists) between numbers and fingers is a topic of much debate.

It is important to remember that the arithmetic our children do in school often requires the manipulation of numbers alone. In order to be able to do this with mathematical understanding, children need to be able to work with numbers as objects in their own right. Hughes[31] suggests that fingers provide children with a very useful tool in this journey, as fingers can model mathematical situations before the child is able to construct purely symbolic statements (e.g. 3+5=8).

It may be useful to consider in more depth, what it is about our fingers that makes them so special. (For the purposes of this review, and to aid clarity, 'fingers' will be taken to include thumbs.) It has been suggested that fingers are particularly important, because they 'possess simultaneously iconic (i.e., features shared with the referent), symbolic (i.e., conventional meaning shared with other individuals), computational (i.e., used to support calculation procedures), and communicative (i.e., used to communicate numerosities through gestures with other individuals whatever their language) properties'.[32] Moreover, what makes these processes truly effective, are the sensory-motor capacities of fingers which enable them to each touch, feel and move, independently of each other. Is this a capacity that we all share?

Fingers, numbers and the developing brain

If fingers are important in developing number representations, are there differences in the ways that adults and children perform tasks involving number? In a recent study involving eight year old children and adults, Kaufmann[43] used brain imaging techniques to explore the areas of the brain that are recruited when performing simple tasks involving judgements about number magnitude. The children and the adults were presented with pictures of two hands with different numbers of fingers on each hand. The task was to identify which of the hands showed more fingers. In these tasks, it was found that although the children and the adults were able to complete the tasks successfully, children took longer. When this was investigated further, it was discovered that this was due to the fact that the children (but not the adults) recruited areas of the brain normally used for fingers. This finding suggests that the use of fingers is an important stepping-stone in the development of an abstract understanding of number, and that finger use should be encouraged to help develop fluency and competence in activities involving number.

Finger gnosis and fine motor skills have also been implicated in supporting the development of arithmetic and mathematical skills.[44] Noel[45] carried out assessments of finger gnosis with children in grade 1 and compared this with an assessment of their skills in mathematics one year later. A correlation was found between the children's level of finger gnosis in grade 1 and their achievements in tasks involving number identification and simple arithmetic one year later. In fact, the relationship between finger gnosis and their achievement in mathematics was stronger than the relationship between tests of general cognitive ability and achievement in mathematics between grades 1 and 2.

Gracia-Bafalluy and Noel[46] found that when children were provided with a finger-differentiation intervention, both their finger gnosis and their numerical skills improved, when compared to a control group. It has been proposed that finger gnosis is a good predictor of maths attainment in typically developing children and that finger representations become more defined as children get older.[47] In typically developing children, finger gnosis develops rapidly up to the age of six years and then continues to develop at a slower rate up to the age of 12 years.[48]

What do we know about mathematical learning difficulties?

The area of mathematical learning difficulties has received more interest in recent years, following a number of reports that have highlighted the impact on life outcomes for adults with poor numeracy skills[49]. In particular, Geary[50] has recently attempted to review much of the literature on mathematical learning disabilities, with the focus primarily on arithmetical knowledge and understanding. Geary is concerned to distinguish between those children who can be characterised as having a mathematical learning disability (MLD) from those who have persistent low achievement (LA) in mathematics. 'Children who score at or below the 10th percentile on standardized mathematics achievement tests for at least 2 consecutive academic years are typically categorized as MLD in research studies, and children scoring between the 11th and 25th percentiles, inclusive, across at least 2 consecutive years are categorized as LA'.[51] Geary is keen to point out that, to date, the mathematical difficulties experienced by children and adults with different levels of intelligence, have not been found to be qualitatively different.

In an unpublished piece of research[52], it was found that the gap between the attainment of children with MLD and typically achieving (TA) children increases as children get older. This is contrary to the gap in reading, which tends to get smaller. On number line activities, in the same piece of research, while the LA children had caught up with their peers by the fourth grade, the MLD group had still not caught up with their TA peers by the fifth grade.

According to Geary[53] children with MLD, and some children who are LA, seem to have a delay or a deficit in number representation and processing. What seems to have been a common finding in a number of studies is the fact that children with MLD and LA use the same approaches to problem solving as their TA peers. What distinguishes all the children with MLD and some of the LA children however is their persistent difficulty remembering, and retrieving, number facts and procedures. Children in grade 1 who have been identified as having MLD or being LA, tend to use their fingers more to keep track of counting in calculations than their typically developing peers. The delay in development is approximately one year for the LA children and two to three years for the children with MLD.

Geary[54] cites studies that have identified difficulties in working memory capacities linked to central executive capacity, phonological loop and visuospatial sketchpad, in children with MLD. These problems could be compounded by difficulties with the inhibition of irrelevant information in working memory in tasks involving information retrieval. There is also evidence to suggest that children with MLD and LA children take longer to solve mathematical problems than their TA peers. However, to what extent this is a consequence of a problem with processing speed is not known.[55]

In looking for reasons why some children are delayed in their mathematical skills and understanding, Price, Mazzocco and Ansari[56] conducted a study that used fMRI to investigate brain activation of 17-18 year olds doing single digit arithmetic. This was then compared with their academic test scores in mathematics. They found that the higher achieving students engaged the part of the brain called the supramarginal gyrus (SMG), while the lower achievers seemed to rely more on the intraparietal sulcus (IPS). It is known that the SMG is involved in perception of time and phonological and semantic processing. As a result of their findings, Price, Mazzocco and Ansari[57] suggest that the SMG may have a role in processing both rhythm and rhyme and may therefore support the learning of arithmetic facts. They argue that this may represent a developmentally more 'mature' mechanism than a mechanism that relies on the IPS, which perhaps supports arithmetic strategies that do not involve the use of learned facts. It is possible that the involvement of the SMG also supports the conceptual development and perception of pattern and relationships.

It seems, then, that there is still much that is not known about the causes of MLD, but what seems clear is that children who experience difficulties with mathematics, and who are identified in school as being delayed in their mathematical development, need individual assessment, as the specific mathematical difficulties that they may exhibit are not all the same.[58]

Conclusions

It would seem that the learning of mathematics requires a complex interaction of physical and mental processes. There appears to be a mechanism by which children learn to make sense of numbers, firstly as tools to support counting and later as abstract entities in their own right. Once children understand that numbers can exist as abstract entities, they are able to begin to explore the wondrous world of mathematics in terms of patterns and relationships whether they exist in the real world, or not. The significance of fingers and an awareness of rhyme and rhythm combined with the capacity of humans to recognise patterns (requiring a combination of perception and memory[59]) provide a varied landscape within which to develop our understanding of mathematics education.

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Music and mathematics: where do they meet?

Caroline Hilton

What are the best methods for teaching mathematics?

This has been a question that educationalists and others have been trying to answer for hundreds of years. However, according to Swan *et al*[1], there are no best methods! The reasons for this are not surprising - children learn in many different ways and mathematics itself is a complex subject. The researchers were interested in looking at what types of learning opportunities were most effective and can be grouped into four common areas. These were:

- Understanding concepts and interpreting representations;
- Developing strategies to investigate novel problems;
- Developing fluency in calculation methods and recall of number facts; and
- Realising the power of mathematics and its role in society at large.[2]

Swan *et al,*[3] then considered which teaching strategies best fostered these types of learning. They found that it was important for children to be provided with opportunities for mathematically rich conversations with their teachers and their peers. They also found that open-ended problems that provided challenge were the best for supporting children to develop their mathematical thinking and understanding. Askew *et al,*[4] found that the most effective teachers were those that supported children to make connections within mathematics, rather than those teachers who relied more either on a transmission (teacher-led) approach, or a discovery (child-led) approach.

There is also evidence that making maths meaningful for children can be very powerful.[5] This could mean, for example, teaching mathematics through stories, through music, or through play. Mathematics in the Netherlands is underpinned by this belief, in order to help children to understand the big ideas in mathematics. It is very important to differentiate this from providing children with 'real world' examples (such as problems involving household bills and banking interest rates), which are often not meaningful to children (as not directly relevant to their 'real world' experience) and can actually have a negative effect on attainment.[6]

Throughout Europe, there is a widespread acknowledgement of a tension between the learning of mathematical knowledge and the development of more fundamental mathematical skills (upon which the knowledge should, of course, be based). If we want to see higher attainment and more positive attitudes, then we need to ensure that we promote active learning and critical thinking in the teaching of mathematics.[7]

According to a recent study, at policy level, central education authorities have some influence on the use of particular teaching methods. Across much of Europe, teaching methods are centrally prescribed or recommended in the majority of countries. In contrast, in Germany and the Netherlands, teachers or schools are only provided with central support in the form of web-based and other resources; and in five countries (Italy, Hungary, the Netherlands, Sweden and Iceland), teachers do not receive any guidelines and it is up to them to choose which methods to use.[8] However, even within these apparently varied contexts, the themes and issues are not that dissimilar.

Mathematical knowledge for teaching

There has been growing interest in what sort of mathematical knowledge teachers need in order to be able to teach mathematics effectively. Askew *et al*[9] found that for teachers in Primary (elementary) education, the qualification of the teacher was not the best indicator of teacher effectiveness in the teaching of mathematics. Williams[10] proposed that teachers of mathematics need to have 'deep' subject knowledge. Ball and Bass,[11] working on the ideas proposed by Shulman that there is a specific pedagogic subject knowledge that is required for the teaching of mathematics, have tried to identify what this might look like. They are clear that this goes beyond knowledge of the curriculum. They have proposed that:

> Although these analyses are ongoing, we see persuasive evidence that the mathematical knowledge needed for teaching is multidimensional. That is, general mathematical ability does not fully account for the knowledge and skills entailed in teaching mathematics.[12]

Low achievement in mathematics

Low achievement in mathematics is a problem for many children across Europe, although less than half of the countries in Europe have investigated the problem in depth.[13] Many reports link mathematics achievement with factors such as socio-economic conditions, education of parents and student motivation. Research evidence on effective educational measures to tackle low achievement underlines the importance of:

- Laying the foundations for mathematics learning as early as pre-Primary level;
- Providing individual support to tackle difficulties as and when they occur;
- Increasing motivation by ensuring that links are established with other subjects;
- Making connections with everyday life; and
- Involving parents with their children's mathematics education.[14]

Mathematics curricula

During the last 10 years, most countries in Europe have revised their mathematics curricula to focus more on skills and competences and less on content.[15] The exception to this is in England, where the recently updated 2014 National Curriculum for Mathematics has the teaching of algorithms and the knowledge of number facts as central to each yearly target, although this is situated within the context of a general statement for the curriculum to foster mathematical reasoning and problem solving skills.[16] In addition, the expectations of the range of number facts and algorithms that children are required to learn in each year of school have significantly increased. Many countries in Europe have made this reduction in mathematics content, in order to be able to make more cross-curricular links and to focus more on problem solving and the application of knowledge.[17]

Across Europe, it seems that mathematics curricula can be broken down into five key areas:

- Mastering basic skills and procedures;
- Understanding mathematical concepts and principles;
- Applying mathematics in real-life contexts;
- Communicating about mathematics; and
- Reasoning mathematically.[18]

Where does music fit in?

Having an overview of mathematics curricula across Europe provides a very useful way of seeing where music can be pivotal for effective mathematics teaching and learning. In very general terms, the context in which mathematics is taught is key to fostering motivation, interest and learning. Music can provide such a context, given that teachers are supported to have both the mathematical knowledge and the musical knowledge, to best exploit this opportunity. The understanding of mathematical concepts and principles, which is key to all the mathematics curricula, involves an understanding that mathematics, at all levels, is usually concerned with an understanding of patterns and relationships. This fits very well within the context of music and, at a very basic level, is the reason that music is often used to support the rote learning of number facts. However, if music is used in conjunction with mathematics, more fundamental relationships can be developed within, for example, the contexts of geometry, number and algebra.

In reviewing the curricula for music and mathematics across Europe, we have tried to consider the bigger picture and look for the common strands where the two subjects overlap. Within the context of this big picture, we can begin to consider how this can be developed to ensure a true integration of the teaching of music and mathematics, where by teaching the subjects as a whole, the understanding of each will be enhanced.

By taking the common themes of:

- Understanding music in terms of aspects such as rhythm, pitch, duration, dynamics, tempo, texture, structure;
- Notation; and
- Composing, creating and improvising…

we hope to begin the journey of piecing together mathematics and music.

Where do music and mathematics curricula meet?

- Understand music in terms of aspects such as: rhythm, pitch, duration, dynamics, tempo, texture, structure

- Count forwards and backwards (in ones, twos, etc.)
- Make connections between number patterns
- Measure and understand time intervals in hours, minutes and seconds
- Compare and sequence intervals of time
- Compare durations of events
- Use non-standard units of measure
- Use position direction and movement, including half, quarter and three quarter turns (rotations); movement in straight lines (translations); line symmetry in 2-D (reflections)
- Order and arrange combinations of objects in patterns and sequences
- Recognise and use linear number sequences
- Generate and use linear number sequences
- Generalise number patterns
- Recognise proportionality
- Identify and use halves and quarters of shapes and objects
- Add and subtract fractions with the same denominator (e.g. ⅛ + ⅜)
- Add and subtract fractions with different denominators (e.g. ½ + ⅔)
- Solve problems involving multiplication and division

Notation

- Identify and represent numbers using objects or pictorial representations
- Use non-standard units
- Identify and represent numbers using alternative representations
- Describe position direction and movement, including half, quarter and three quarter turns (rotations); movement in straight lines (translations); line symmetry in 2-D (reflections)
- Use a variety of language to describe and understand multiplication and division
- Order and arrange combinations of objects in patterns and sequences
- Recognise and describe linear number sequences
- Generate and describe linear number sequences
- Generalise number patterns

Compose, create and improvise
These could include all of the above!

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Music and Mathematics:

a neuroscientific perspective

Liisa Henriksson-Macaulay, Graham F Welch and Jo Saunders

Background: the presumed links between music and mathematics in education

Throughout the history of mathematics, its relationship with music has provided a source of fascination for those at the forefront of Western thought. The Ancient Greek mathematician Pythagoras, the forefather of the Pythagorean Theorem, is credited with discovering that, when musical notes sounded harmonious together, they corresponded to simple mathematical ratios. Modern research describes this finding thus: "Across all cultures, pitches whose fundamental frequencies stand in small integer ratios (e.g. octave, 2:1; perfect fifths, 3:2) form consonant intervals, and elicit more positive affective responses than pitches whose fundamental frequencies stand in more complex ratios (dissonances: e.g. tritone, 45:32)".[1] In other words, the pitches of music that sound in-tune stem from simple, fundamental mathematical relationships.

Music, therefore, is not merely man-made culture. Its roots are in physics and the laws of nature itself. In this section of the review, we will explore some of the connections between music and mathematics drawing upon the available neuroscientific evidence.

As neuroscience concerns itself with how the human brain functions, the theory of evolution is highly relevant. The way that the human brain has adapted to process mathematics and music is of prime importance, and, to date, there are still unanswered questions. However, there exists a general scientific consensus concerning the timelines around which these abilities first appeared amongst the human race. Evidence suggests that humans have made music for 500,000 years. In comparison, humans developed spoken language 200,000 years ago. It has been proposed that language development depended upon those aspects of the brain that also made it capable of making music.[2] Could the same be said for mathematics; that the human brain's capacity for mathematics developed based upon its musical capabilities? It is worth considering that, perhaps due to music skills having survived in the course of evolution for half a million years, it is now being suggested by neuroscience that *music making activates more parts of the brain than any other activity*.[3] It could be proposed that our brains have built themselves around music.

On the other hand, mathematics is, in terms of human evolution, considered to be a relatively novel introduction within the sphere of activities of the human brain. At only 6000 years old, in the evolutionarily perspective of vast timelines, the invention of mathematics is perhaps as novel for our brain as, for instance, space travel. The evidence suggests that the high cognitive ability of the human brain predates the engagement in such activities and there is an accumulation of scientific evidence to suggest that music training facilitates the human brain's high-level cognitive abilities to a degree unparalleled by other forms of learning.

The fundamental components of music can be considered primarily as pitch and rhythm. Both are fundamentally linked to the physical world, at least in the way that humans and other biological organisms structure time. The fact that animals such as mammals and birds seem to be programmed to use pulse (a sequence of beats) seems obvious from just observing the way that they walk (or fly): the coordination that a dog uses for walking or running, or a bird for flying, requires a sense of a steady pulse, which is a prerequisite for rhythm. Pulse (as a sequence of regular beats) is also a feature that distinguishes music from random sounds. In its simplest definition, it could be said that music is sound organised to a beat. Even insects such as fireflies have been observed to use a steady pulse when they communicate with each other through flashing a light.[4]

The mathematical components of rhythm and beat have acquired equal fascination amongst the great thinkers of Western cultural history. The 17th Century mathematician Leibniz, who co-discovered calculus, wrote that, 'Music is the pleasure the human soul experiences from counting, without being aware that it is counting'.[5] The links between music and mathematics have not simply been theorised about, but music has been used as one of the cornerstones of mathematics education since such education first began. Although mathematics was used in practice by earlier cultures such as the Inca and the Egyptians, the first people to embrace mathematics as a science worthy of study in its own right were the Ancient Greeks. To them, mathematics education was divided into four subcomponents: number theory, geometry, astronomy and music. This placement of music within the teaching of mathematics was embraced in the teaching of the *quadrivium* (arithmetic, geometry, astronomy and music) from around the 6th Century and lasted until the end of the Middle Ages in European cultures. Since the time of the Renaissance, music has been established as its own subject, although leading mathematicians of each era continued to be fascinated with the theory and practice of music.

The purpose of this literature review is to evaluate what, if anything, the study of music has to offer for the teaching of mathematics, according to the most recent scientific research from various fields such as education, psychology and neuroscience. If music is inherently mathematical, as is traditionally theorised, could it be used to improve education outcomes in Primary school mathematics and, if so, how?

The Mozart Effect: a scientific myth and media sensation

In the early 1990s, amongst budgetary cuts for the place of music at schools, a study published in the prestigious journal *Nature*[6] was the starting point for a revived interest in the place of music for mathematics. Educators, parents and politicians alike were fascinated to read about a study that showed that simply listening to Mozart before taking a cognitive test was enough to boost the scores of the participants in the mathematically relevant spatial-temporal component of the test. This phenomenon of boosting the spatial-temporal scores (albeit on a short-term basis) was dubbed 'The Mozart Effect' and was widely reported across the media. The seemingly widespread acceptance of the benefits led to some politicians in the United States seeking to ensure that every newborn child in their respective States were offered a classical music CD upon their birth, in order to boost their cognitive development.[7]

However, a large amount of further scientific research has challenged the assumption that the 'Mozart Effect' provides any cognitive enhancement. What has been found instead is that the original short-term IQ boost appears to have nothing to do with the music itself. Leading researcher E. Glenn Schellenberg, for example, reports that it is mood enhancement rather than the musical source itself that mediates a short-term cognitive improvement, whether in spatial-temporal skills or elsewhere, and that similarly improved results were found when participants had listened to a Stephen King story before taking the test.[8] A subsequent study by Schellenberg and Susan Hallam, undertaken with 8,000 children aged 10-11 years, found that the Primary school aged children did not experience a spatial-temporal score increase from listening to Mozart or other classical music, but that they did experience it after they had listened to the popular radio hits of the day instead.[9]

One of the original 'Mozart Effect' researchers, Frances Rauscher wrote in the aftermath of the Mozart media frenzy, 'The original research report (...) received a disproportionate amount of attention from the popular press. To our horror, the finding has spawned a Mozart Effect industry that includes books, CDs, web sites and all manner of hyperbole. (...) There is no evidence for the claim at all that listening to classical music CDs improves children's spatial-temporal reasoning or any other aspect of intelligence. (...) The scientific reports made no claims about general intelligence, SAT scores, or babies.'[10]

Cognitive scientist Elena Pasquinelli reports that the 'Mozart Effect' became a 'neuromyth' - a phenomenon that is scientifically shown to not exist, but one that nevertheless is in circulation amongst the wider public, including some educators and researchers. She writes: 'Despite the absence of evidence, in 2004 80% of 496 people interviewed in California and Arizona were familiar with the Mozart effect [,] and products based on the Mozart Effect are sold in millions of copies'.[11]

A similar 'neuromyth' could be the belief that background music—music played in the background when the listener is simultaneously engaged in cognitive activities—engages performance in cognitive tasks or tests. Although there is some evidence that, at least for some pupils, playing background music may be helpful,[12] it is also reported that listening to music, whilst engaging in another task, depletes the brain's working memory. This is counterproductive for both tasks.[13] Therefore, listening to background music is not necessarily a supportive activity for mathematical thinking.

One way that has been reported of using music to help with an aspect of mathematics relates to singing songs in order to help memorize times tables content. In some European countries, this is described to be a predominant way of integrating music with mathematics. The report from Switzerland states, "When used in math lessons in lower grades, music is often regarded solely as a helping tool to learn multiplication tables by heart (e.g. Maurer-Früh, 1995). The approach generally does not reach beyond that (Cslovjecsek: 2006)."[14] While songs or song-like chants may be extremely effective in memorising, this technique appears to relate to learning-by-heart (or rote learning) rather than assisting the logical and cognitive processes that are at the heart of real mathematical development. Being able to recite 3-6-9-12-15-18 does not yet imply that the pupil understands the concept and processes of multiplication. Yet, as reported below, music has so much to give when it comes to facilitating actual mathematical thinking.

Pasquinelli warns that neuromyths 'can do more harm than good',[15] that as in the case of the 'Mozart Effect' could be true if educators become disillusioned with the idea that music can offer any extracurricular benefits at all. As outlined in the next section, a wealth of evidence has indeed started to emerge since the late 1990s suggesting that music can significantly improve the mathematical learning of pupils - but only when the pupils actively engage in musical activities, as opposed to passive music listening.

Evidence for a cognitive transfer from music training to mathematics

The 'Mozart Effect' myth, however misunderstood or misapplied, can be given credit for stimulating a research trend that began to examine the extent to which engaging with music might lead to wider cognitive benefits. Pasquinelli quotes Carl Sagan, who states 'there are many hypotheses in science [that] are wrong. That's perfectly all right; they're the aperture to finding out what's right. Science is a self-correcting process. To be accepted, new ideas must survive the most rigorous standards of evidence and scrutiny.'[16]

Unlike the historical theoretical perspectives previously stated, contemporary scientists have access to cutting-edge research methods such as brain imaging technologies and advanced research procedures. These enable neuroscientists to gain greater insight into the actual links between musical and mathematical thinking. One of the more recent concepts to have emerged within neuroscience is that of *cognitive transfer*. Cognitive transfer is based on what is now known about brain function: that each part of the brain has the potential to engage in several tasks, and if a person engages in an activity that develops a particular neural region, they may simultaneously gain an advantage in some other areas that are networked in the neural processing to that particular region. As an example, it is reported that bilingual individuals (those who grow up with not one, but two mother tongues) have enhanced executive function within the prefrontal cortex. This cognitive transfer is thought to occur as a result of early experiences during which a young child frequently switches from one language to another, according to context and the caregiver that they are communicating with.[17]

The question 'does music learning improve mathematical skills?' could, therefore, be rephrased, as 'is there a cognitive transfer from music learning to mathematical skills?' There is both empirical and other neuroscientific evidence to suggest that such a transfer is possible. In considering the empirical evidence, there are several studies since the late 1990s that report a correlation between a pupil's musical learning and their mathematical skills. For example, a study in 1998 found that students who had had private instrument tuition for two years or longer performed better in a standardised mathematics test than their peers who either had had no music tuition, or had engaged in it for less than two years.[18] Another mid-1990s study concerned itself with pupils who started on a lower level in mathematics compared to their peer group. After nine months of training in music and arts, they had surpassed a control group's mathematics scores,[19] a finding which was found in later analysis to relate to the music learning and notation effect specifically.[20] More recent research found that pupils who engage in instrument learning have consistently better school grades 'in every subject and in every level',[21] a finding that is verified by other similar studies.[22]

One challenge in the interpretation of these studies is the predominance of music education as conceptualised through the specialist model in which pupils participate in private music lessons. Such provision of 1:1 or small group tuition is likely to be relatively expensive and, therefore, higher school grades may coincide with those families that have higher socio-economic status, a factor that is already considered to give children an advantage in academic scores in and of itself. However, researchers who have taken the socio-economic status of families into account in the analysis of their data report that music learning *does* provide an independent boost for academic scores. Wetter *et al* note that 'interestingly, the predictor music still proves highly significant after the other predictors are held constant'. The researchers further note that in their study, there were no significant family income differences between the children who practised music and those who did not.[23] Similarly, Kate Fitzpatrick found in her study that the children from lower socio-economic backgrounds who practised music ended up academically surpassing their peers from higher socioeconomic backgrounds who did not practise music.[24] These research findings would seem to suggest that the academic advantage gained as a result of music learning couldn't be explained away by family background alone. How could music learning give children a distinct cognitive advantage? In the following section, we shall consider the different mechanisms by which the transfer from music skills to improved academic skills may take place, particularly in relation to mathematics.

Neuroscientific evidence for a cognitive transfer from music to mathematics

The new millennium has witnessed a surge of research interest from neuroscientists, psychologists and educators alike into the effects of music within the brain. In 2002, neuroscientists Munte, Altenmuller and Jancke declared in the prestigious journal *Nature* that the musician's brain is an ideal model of *neuroplasticity*. Neuroplasticity refers to the brain's ability to restructure itself based on the stimuli that it is given. The scientists wrote of their fascination with the 'functional and anatomical differences that have been detected in musicians by modern neuroimaging methods'.[25]

Around the same time, it was noted that musical engagement appears to activate more parts of the brain than any other activity. As music activates a wealth of regions in the brain, and music learning is shown to restructure the brain in ways that are visibly detectable by brain imaging technologies, it could be hypothesized that music learning would influence a multitude of brain regions. This is indeed what research findings suggest. Music learning has been shown to lead to improved neural connections in all the main areas of the cerebral cortex, including the prefrontal cortex (the same advantage that was reported earlier in bilingual individuals). However, the effects of music learning do not end there as they are also detected in regions of the brain that deal with memory, emotion, movement, visual stimuli and language.[26]

In a similar vein, there is preliminary evidence that music training enhances those areas of the brain that deal with mathematics. Neuroimaging research into the brains of mathematicians has found that years of engaging in high-level mathematics are likely to increase the neural connections in the inferior parietal lobule, a region in the cerebral cortex that is also known from other studies to deal with arithmetic problem solving.[27] The phenomenon of neuroplasticity is evident here as practising arithmetic activates the inferior parietal lobule, which in the long run leads to physical changes in that region of the brain and its neural networks. The apparent tautology that 'practising mathematics makes you better at mathematics' is thus explained by neuroscience.

What is perhaps more surprising is that neuroscientific evidence also shows that music learning also produces detectable changes in this 'mathematical region' of the brain.[28] This could explain a cognitive transfer from music learning to improved mathematical performance. How does music learning activate this 'mathematical region' of the brain? To answer this question we must first remember that, in terms of human evolution, mathematics is a relatively recent activity. It is proposed that the human race has not been engaging in mathematical activity long enough for it to have impacted the way the human brain is biologically arranged and, as such, there is no place in the brain that has evolved specifically for arithmetic or any other type of mathematics. We must, therefore, look at those functions of the inferior parietal lobule that pre-date the invention of mathematics in order to find out what that part of the brain has, over the course of human evolution, adapted.

Neuroscientific evidence suggests that the inferior parietal lobule deals with spatial cognition and visuomotor integration,[29] both of which have critical survival implications for our ancestors. Assessing the threat of a predator, the speed at which they are travelling and executing a successful escape strategy all rely upon spatial cognition and visuomotor coordination. These may, therefore, be the neural bases that have subsequently enabled mathematical ability to emerge as part of the human condition.

In the light of this knowledge, it becomes easier to see how the cognitive transfer from music learning to mathematics might take place. As is often noted in research regarding music and mathematics, musical notation is itself, spatial. Therefore, engaging in playing music from notation could plausibly activate the inferior parietal lobule, which upon sufficient repetition could improve the neural connectivity in this region, in a similar way to that of mathematical practice.

What is more, playing music from notation is itself an exercise in visuomotor integration. When playing from a written score (of whatever format) the musician engages in a complex task of transferring a string of visual stimuli onto precise physical movements, so as to produce the intended sounds. As one might expect, music education is shown to improve visuomotor coordination.[30] What is of particular relevance to the teaching of mathematics is the evidence that the better a child's level of visuomotor coordination, the higher their mathematical skills level.[31] As a result, the link between music learning and improved mathematical skill is implicated not just at the neural, but also at the behavioural level.

According to a subsequent analysis of the Gardiner *et al* (1996) study (reported above) on the benefits of music learning for mathematics achievement, it was the notational ability in particular, as opposed to musical performance ability that produced the notable improvements in both the mathematical and reading scores of elementary school pupils.[32] It could be argued that learning musical notation is an effective way of improving the mathematical performance of young pupils.

It would, however, be unwise to suggest that the symbolic representation of music (the score or notation) should predominate over the sounds that it describes. It is also worth noting that, from the point of view of brain development within human evolution, musical notation (in whichever form) may be an equally novel skill for the human brain as mathematics. Unlike notation, it is believed to be the factors of rhythm and melody that have persisted in the human race over the past 500,000 years. Following this line of argument, it would appear to be implausible that musical notation gave rise to mathematical abilities; if anything, the suspects are rhythm, melody, or both. One possible explanation from research evidence is the preliminary findings of links between rhythmic skills and intelligence.[33] Intelligence in these studies was determined by standardised assessments of IQ and the results of these correlate robustly with levels of mathematical skills and achievement.

Consequently, there is insufficient research data to determine whether learning notation improves mathematical thinking as such. It could equally be hypothesized from Scripp's analysis that the children who performed better at understanding notation did so because of a pre-existing ability of understanding symbols, and that it is this ability that can utilised for mathematical concepts, alphabetic letters and musical notation. Without further evidence, it would be mistaken to emphasise the notational aspects of music learning over active engagement in making music aurally. However, as the existing neuroscientific and behavioural evidence suggest a likely robust learning transfer from musical learning to visuomotor integration on one hand, and from visuomotor integration to mathematics on the other, it becomes evident that learning the basics of playing from notation should be an integral part of lessons in music and/or mathematics, whilst bearing in mind both pedagogically and psychologically that 'sound should come before symbol'.[34] In practice, the use of musical notation may not be widely prevalent in many Primary schools, unless they have an extensive musical instrument-learning programme, not least because the music teacher is often the responsibility of a generalist elementary school teacher, who may or may not have had any formal music education in instrumental performance. Many teachers would need additional training in notation reading, but this task is nowhere near as daunting as it may seem. Clapping rhythms made up of quavers and crotchets in varying orders, and playing simple melodies on an instrument such as the xylophone or its metallic version the glockenspiel may be easy for any Primary school teacher, even a relatively musical novice, to pick up, and therefore to teach to their class, especially if the teacher (and her pupils) start with self-invented means of notation before introducing more standard notation symbols.

The auditory scaffolding hypothesis: a new theory for learning

The 'auditory scaffolding hypothesis' is a recent theory based upon evidence from various scholarly areas. According to this hypothesis, not all senses are equal when it comes to effective learning, but rather the auditory pathway is considered to play a central role. In experimental studies, researchers report that humans learn up to twice as effectively through sound than when the same information was presented by visual or kinaesthetic means.[35]

Further evidence supporting the auditory scaffolding hypothesis comes from studies regarding children with hearing impairments (HI). When presented with visual information, the research found that whereas half of children with normal hearing were able to spot the patterns in the data, only one third of HI children with cochlear implants did so. Furthermore, the longer the HI children had experienced auditory deprivation during their childhood, the more their visual pattern recognition suffered, and 'correspondingly, the longer the child had experience with sound via the [cochlear] implant, the higher their sequence learning scores.' The researchers hypothesized the auditory medium to be the principal way in which children learn the skill of sequencing, in other words, of recognising patterns.[36]

The auditory scaffolding hypothesis is a relevant focus of study with regards to the teaching of both mathematics and music. First, the theory proposes an implied importance of sound to the learning of mathematics, because understanding mathematical operations involves dealing with patterns. Customarily, the study of mathematics is undertaken in Western societies principally via the visual or kinaesthetic medium. The recent research relating to the auditory scaffolding hypothesis may have profound implications for how mathematics can be taught most effectively.

Secondly, if the auditory scaffolding hypothesis is correct, it could explain why music learning has such a profound effect on different areas of the brain, as is evidenced in current neuroscientific research. If sound is indeed the most effective medium through which the human brain gathers and organises information, this could explain why sustained music learning appears to give children a general advantage in various cognitive areas, including mathematics as well as other academic subjects. Leading neuroscientific research from Northwestern University in the USA has established evidence that on one hand, musical training restructures the brain's ability to hear better, on both a conscious and automatic level; and on the other hand, a better ability to process auditory information that gives humans a distinct advantage in general cognitive processing.[37] In European research, it is similarly reported that musical and auditory-based approaches produce superior results in mathematics when compared with standard ways of teaching.[38] Furthermore, a series of studies at Harvard University suggest that intensive music training is associated with improved performance in the core mathematical system for representing abstract geometry. Controlling for an array of other variables (such as IQ, academic performance, social and economic factors), the team found that intensively music-trained students outperformed others (with little or no music training) at detecting geometric properties of visual forms, relating Euclidean distance to numerical magnitude, and using geometric relationships between forms on a map to locate objects in a larger spatial layout.[39]

Thirdly, if the auditory scaffolding hypothesis is supported, there are implications related to the perceived value and time allotted to music within the Primary school curriculum. If the auditory medium is indeed the principal medium through which pupils learn most effectively, and, if auditory education has widespread positive implications for the intended cognitive outcomes of the academic curriculum, it could be argued that music learning should be central to curriculum design as it represents the most effective way to develop a child's and their brain's auditory skills. The auditory scaffolding hypothesis also offers an explanation to the research finding that unlike from music to mathematics, there appears to be no clear cognitive transfer from mathematics *to* music.[40]

A caution regarding a potential critical age for maximum cognitive transfer

Research evidence regarding children who are born deaf suggests that if they receive cochlear implants during their first years of life, their cognitive abilities can be developed to the same level as their normal-hearing peers, whereas after the age of seven, the plasticity of the brain appears to be reduced.[41] There is also research evidence that suggests that at least some of the extra-musical cognitive effects of music are similarly dependent upon the age when formal music learning is started.

Drawing on neuroscientific evidence, a study with adults reported that musicians who start formal music learning before or at the age of seven have thicker neural connections between the two sides of the brain (this neuronal tract is called the corpus callosum), but that musicians who have started after the age of seven do not differ in this respect from non-musicians.[42] Subsequent research (2005) by the same team with children aged five to seven found no significant pre-existing cognitive, music, motor, or structural brain differences between children learning an instrument and those not, but difference began to emerge after fourteen months of instrumental learning. These differences were more marked in a comparison group of child instrumentalists aged nine to eleven.

In addition, empirical research suggests that when children start music training at age seven or earlier, their measurable IQ improves significantly, particularly those involved with singing.[43] IQ tests, according to Howard Gardner's Theory of Multiple Intelligences, principally deal with logical-mathematical intelligence.[44] Therefore, yet another pathway for cognitive transfer from music to mathematics could be that related to whatever is being measured by IQ assessment. However, it is unclear whether there is an IQ increase when a child starts music learning if they are older than seven years old, and the age of participants should always be kept in mind when interpreting empirical research. There is some evidence for music-to mathematics transfer in children over the age of seven.[45] However, conflicting findings, such as those described in Costa-Giomi's 2004 study, reports that nine-year-old pupils who embarked upon a three year long programme of piano lesson did not gain cognitive benefits.[46] As the emergent research findings would seem to indicate that cognitive transfer is potentially age-sensitive, several researchers recommend, as a practical guideline, that children start formal music learning as early as possible.[47]

Contrary to the potential age sensitivity of music learning in children, it has also been established that music training improves working memory at any age (throughout adulthood and beyond) as neuroplasticity has been evidenced across the lifespan.[48] Working memory is reported to play a crucial role in mathematics, as it allows the brain to process numbers, calculations, data and generally any kind of information more efficiently. When 10-year old children engaged in music training for two years, their working memory was found to improve[49], a finding that is supported by other research[50]. Interestingly, the Roden *et al* 2014 study used science training as a control activity and only music training improved working memory[51].

The evidence would appear to suggest that music learning is a curriculum subject that can support the development of other academic abilities. Whilst further research is needed, the current state of neuroscientific and educational research generally points towards the conclusion that music learning at the Primary school level (and earlier) is likely to support mathematical as well as other academic outcomes, and offers several plausible and interacting transfer mechanisms for this phenomenon, from brain imaging evidence to the importance of the auditory functions as outlined in the auditory scaffolding hypothesis.

Music learning: what kind?

So far this part of the review has focused broadly on 'music learning', but it is necessary to examine the concept in more detail so as to disseminate what specific elements of music education may be more beneficial or most effective for a cognitive transfer to mathematics. Most research has concerned itself with instrument learning.[52] However, there has been equally successful group music learning options acquiring the same beneficial effects.[53] The study by Moreno *et al* from 2011 demonstrated a measureable IQ boost after the participant pupils had worked with a computer-based music-learning programme.[54]

The common denominator across these studies is that the participant children learned musical *skills*. In practice, there is some evidence that standard school music classes may not focus sufficiently on building music skills, but instead contain rather too much talk about music, or an overemphasis on listening to music.[55] When researchers have compared the cognitive results from standard school music classes to those where there have been specific music skills interventions, it has been reported that only the latter produced significant cognitive benefits.[56] When research has focused on listening to music, playing (with toys) to music or moving to music, no cognitive benefits have been found.[57] Researchers note that 'these data show that the activities usually held in elementary school classrooms for the curricular subject Rhythm, Songs, and Games did not affect the vocabulary development of the children in our sample. The activities must be primarily musical in nature and must have the specific objectives of discriminating sounds and forming auditory-visual associations.'[58]

What would these musical activities look like? How do we distinguish between a musical activity and an activity about music? To answer this question, we must return to the beginning of this section of the review. Music consists of several core elements, including rhythm and pitch/melody/harmony. Rhythm is sound arranged by time sequences; melody and harmony are sounds arranged by pitch frequencies. In general, to learn music, one must learn to manipulate such elements effectively. In its simplest forms, practising moving to a steady pulse, clapping beats and more complex rhythms, and playing simple percussive instruments, can enable a child to learn the skill of rhythm. The skill of melody can be learned by, first and foremost, its most effective natural expression: singing. Additionally, based on Finnish experience in their pre-school programme, simple instruments such as the glockenspiel, xylophone or the lyre, are accessible means for young children to begin their instrumental journey. There are, in addition, the possibilities offered by musical symbolisation through notation. It is generally agreed upon by music education researchers that, whilst basic notation is good to teach it needs to follow experience in sound. With the growing interest in the educational community towards embodied mathematics, music may well be the most obvious route to achieve this embodiment.[59]

Music Curricula in Schools

Jennie Henley and Jo Saunders

How are music curricula structured?

Music curricula are divided into two broad main types of managed curricula: national curricula and devolved curricula. Within these, there are different levels of specification, from explicit programmes of study to more general learning aims. Each country has its own expectations as to how far a teacher needs to interpret the curriculum. This to some extent is dependent how the curriculum is structured.

'Key skills' as described within the national curricula

Most national curricula comprise the broad areas of composing, performing, and listening and appraising. Although there are commonalities in the areas contained within curricula, there are differences as to the amount of guidance and prescription given to schools. For example, in 2013 the English National Curriculum was revised.[60] The level of specification as to what children should study was greatly reduced, providing schools instead with a broad framework through which to develop their own curricula for music. The resultant music curriculum for both Primary and lower Secondary settings (i.e. for the duration of compulsory music education) is based on a list of aims concerning musical behaviours that children should be able to demonstrate. These include (i) performance; in which the child should be supported so as to listen to, review and evaluate music from a range of historical periods, genres, styles and traditions, including the works of great composers and musicians[61]; (ii) singing and the use of the voice; so that the child is able to create and compose music on their own and with others, have the opportunity to learn a musical instrument, use technology appropriately and have the opportunity to progress to the next level of excellence; and to be able to (iii) understand and explore how music is created, produced and communicated, including the inter-related dimensions of pitch, duration, tempo, timbre, texture, structure and appropriate musical notations.

The music curriculum contains statements as to what school children should be taught within Key Stage 1 (children aged 4-7 years old), Key Stage 2 (children aged 7-11 years old) and Key Stage 3 (children aged 11-13 years old).[62] Unlike other subject guidance, the documentation relates to 'key skills' rather than domains of study (for example, as given for mathematics). There is a sense of sequential development inherent within the framework as the same broad areas are revisited over time so as to build upon (gain breadth) and refine (gain depth) the key skills. For example, during Key Stage 1, children are expected to 'use their voices expressively and creatively by singing songs and speaking chants and rhymes' and 'play tuned and untuned instruments musically'. At Key Stage 2, these separate statements are described as 'play and perform in solo and ensemble contexts, using their voices and playing musical instruments with increasing accuracy, fluency, control and expression.' At Key Stage 3, the expectation is that the children will 'play and perform confidently in a range of solo and ensemble contexts using their voice, playing instruments musically, fluently and with accuracy and expression.' From an initial focus on encouraging the expressivity and creativity, the emphasis shifts towards confidence, accuracy, fluency and, finally, expression. Similarly, initial descriptors concerning improvisation and composition from Key Stage 1 states that children will 'experiment with, create, select and combine sounds using the inter-related dimensions of music' which translates into 'improvise and compose music for a range of purposes using the inter-related dimensions of music.' By Key Stage 3, the requirement is that the children will 'improvise and compose; and extend and develop musical ideas by drawing on a range of musical structures, styles, genres and traditions.' In some cases, key skills introduced during the earliest Key Stages are further subdivided as the child ages, for example, the initial statement to 'listen with concentration and understanding to a range of high-quality live and recorded music' is mirrored in Key Stage 2 in 'listen with attention to detail and recall sounds with increasing aural memory' and Key Stage 3 in 'listen with increasing discrimination to a wide range of music from great composers and musicians.' However, at Key Stage 2, this is supplemented with a need to 'improvise and compose music for a range of purposes using the inter-related dimensions of music' and by Key Stage 3 develops into 'appreciate and understand a wide range of high-quality live and recorded music drawn from different traditions and from great composers and musicians.' These selected examples, illustrate the way that particular musical skills are identified as 'key skills', and, by so doing, identified as areas for continuous development over the duration of Primary and lower Secondary schooling.[63] The reader will appreciate the way in which the same threads of musical skills are retained throughout the Key Stages. To a great extent, the division between Key Stage 1 and 2 (Primary) and Key Stage 3 (lower Secondary) exists as a result of the transition between types of schools rather than as a stated reconsideration of the nature of music education as proposed by the curriculum. In many English Primary schools a non-specialist teacher often teaches music, whereas in Secondary schools the music teacher is most often a music specialist. As in many other countries, attempts have been made to design a music curriculum that encompasses broader musical learning and includes playing an instrument and singing, as well creating music and developing understandings of musical culture and context.

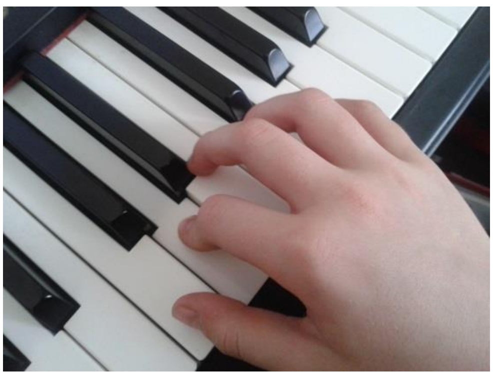
National curricula for music in the countries of the UK have been revised a number of times[64]. In previous versions of the curriculum, attainment targets were outlined that gave teachers an indication of expected musical progression through the curriculum. The 2013 revision removed these attainment targets.[65] This was to allow schools to develop their own understanding of musical progress, based on the particular musical strengths of the school. Unfortunately, whilst seeking to empower schools and teachers to individualise their teaching and learning, this has also resulted in a national curriculum briefing that lacks sufficient guidance so as to enable teachers to (i) implement the curriculum; (ii) approach the activities; (iii) what the teacher's role might be; (iv) the relationship between and across activities.

Many countries have subsequently modelled their National Curricula on the English version(s). As the English curricula have received criticism, been reviewed by government departments and been revised, other countries have also recognised the need to examine their practice.[66] For example, rather than compartmentalising the areas of composition, performance and listening, some countries have developed a more integrated curriculum. These types of curricula often acknowledge the relationship between the curriculum and assessment, and give explicit guidance for teachers and exemplars to be used in practice. An example from Hong Kong[67] demonstrates how this can be achieved through adopting *assessment for learning* strategies.[68] Through a process of peer and self-assessment, children are believed to be able to develop musical experience as well as knowledge and understanding of music. Performance of their own compositions is seen to enable children to listen and appraise their work, thus meeting the requirements of the integrated curriculum. Schools are encouraged to interpret the central curriculum, and guidance is given for curriculum planning, learning and teaching activities, assessment, and learning and teaching resources. A vital part of this approach is active music making.

Other national curricula have varying amounts of prescribed content. The Estonian and Finnish National Curricula have much in common with one another[69]. The curriculum in Estonia has seven central musical activities and provides schools with learning outcomes for each age group within each activity. These seven activities also contain composition, performance and listening, but with the addition of musical movement. The Finnish National Curriculum has similar content including reference to musical movement. However, only general aims and objectives are provided and within the Finnish context, the published guidance operates as a broad framework for schools to develop their own, detailed curriculum.

In both Estonia and Finland, European pedagogical methods such as those developed by Orff, Kodály, Suzuki, Jaques-Dalcroze and Pätts are widely used. These provide the teacher with a toolbox of methods that they can employ to carry out the activities described within the curriculum. Although they have quite distinct approaches, the commonality across each of these methods is that they stem from a fundamental principle that *all children can and should benefit from musical instruction*[70]. Therefore, the teacher can choose activities using different approaches whilst still ensuring that the general philosophy of the curriculum is maintained.

Opportunities for integration across different subject areas are afforded by curricula where music is housed within a larger curriculum area. In Finland, music is part of a subject-group alongside visual arts, crafts and physical education. The core content and objectives of the music curriculum have been developed alongside these other subjects. In South Africa, music falls within Arts and Culture along with dance, drama and visual arts. Teachers are expected to incorporate expressive arts into other areas such as numeracy and literacy.[71] As described in Estonia and Finland, movement and musical learning are closely aligned.



However, grouping with other subjects does not necessarily mean integration in either curriculum design or practice. In Spain, the curriculum is part of an 'artistic area' and coupled with visual arts. The two subjects share the same general objectives, but there are distinct criteria for each subject. This can produce a more isolated music curriculum rather than an integrated arts curriculum.[72] Although movement and dance are part of the curriculum, there is no crossover in practice to integrate visual arts into dance and movement activities.

Some national curricula seek to promote the integration of generic skills (such as teamwork, evaluation and critical thinking) in the form of core skills that apply across the curriculum subjects. An example can be seen in the Scottish National Curriculum. Teachers are expected to teach core skills, including (i) critical thinking and problem solving; (ii) working with others; and, (iii) information and communication technology (I&CT).[73] Curriculum activities such as composition and performance may well facilitate working with others.[74] Evaluation and problem solving skills are fundamental to creative activities.[75] Some teachers believe that music affords the perfect opportunity for students to develop skills beyond basic I&CT skills, such as word processing. Other teachers believe the lack of standardisation of the implementation of the music curriculum means that it is impossible to develop a uniformed approach to the integration of the music and I&CT core skills curriculum.

Reviewing national curricula in different countries shows that although the curriculum activities may be similar, there are vast differences in the level of autonomy given to schools and teachers. Also, there are differences as to the scope for variety of content given by each curriculum. An argument for a 'national' curriculum of music may be that it would ensure equity within musical activities and musics studied. This might result in a classroom full of different types of creative activities and a range of music that resonate with different children. Introducing Rock and Pop music has opened the door for technology to be used in the classroom, for example.[76] There are implications for teachers, however. Research has shown that a lack of knowledge of different types of music has produced a situation where only certain music is taught. For example, in South Africa there is little indigenous music taught.[77] Research has also shown that national curricula have been found demanding in content[78] and there are arguments as to how far a generalist Primary teacher can cover such a wide range of musical experience.[79]

It has been suggested also that the successful implementation of a national curriculum will depend on who is teaching it.[80] Therefore, what happens in practice may be very different to what is stated in the curriculum.[81] However, a curriculum should not necessarily to be conceived as a 'top down' process.[82] Many national curricula act as a guide rather than a specification. Schools have flexibility within curricula to choose the musical activities and strategies that best suit their pupils.

Devolved curricula

The Taiwanese curriculum is decentralised and schools are expected to develop their own curriculum.[83] This means that teachers also have to take on the role of curriculum developers. Teachers can no longer teach from a national textbook, but they need to think about what, why and how they teach. Unlike a national curriculum where core values are (in principle) already established, schools and teachers need to make decisions as to what these values should be. As a result, there is likely to be less standardisation of values across different schools. Each Primary school curricula in Taiwan must align with the government's Developmentally Appropriate Practice (DAP) agenda for early childhood.[84] This agenda states that all curricula for children from birth to 8 years old should be (i) child-centred; (ii) consider individual child development, needs and interest; (iii) consider individual cultural context; (iv) be constructed to represent a holistic perspective; (v) focus on play; (vi) provide a supportive social environment and social interaction.

Irrespective of local variation, schools need to develop a curriculum that is *firm enough to achieve musical learning without losing children's interests, and also flexible enough to allow children to freely connect with their experiences*.[85] An example of this approach using the voice, would involve singing activities centred on enhancing children's voices rather than learning songs by rote. This could include vocal improvisation as well as exploring suitable repertoire. Within instrumental learning, an activity might be centred on the child's understanding of pitch and duration. Teacher-led activities might be used to introduce musical concepts, with musical free play following so as to allow children to develop these creatively. However, irrespective of the specificity of the curriculum, the practical implementation and classroom experience of children is largely dependent upon who is teaching music. In reality, many national curricula do devolve the responsibility for developing curriculum content to the school. The difference between national curricula and devolved curricula is who decides what music and what musical activities are valued above others. In reality, who decides what kinds of knowledge and understanding children are expected to develop is likely to be the responsibility of the individual(s) that actually work alongside the children in the classroom context.

Summary

The evidence presented would suggest that:

- Most curricula contain composition, performance and listening in some form;
- Some countries include movement and dance in their music curriculum;
- Some countries include core skills, such as teamwork or problem solving;
- There are differences in the level of prescription given in national curricula;
- Some countries organise their music curriculum in an integrated way;
- Some countries organise their music curriculum alongside other arts subjects;
- Organisation of subjects does not necessarily mean integration;
- Devolved curricula often still require schools to adhere to a national agenda;
- Many of the challenges involved in the implementation of curricula are concerned with *who* is teaching music.

What kinds of knowledge and understanding do music curricula develop?

There is a divide in many countries between learning to play an instrument or learning to sing, and learning music in a much broader sense.[86] Some curricula are skills-based, aimed at learning to play music, and some curricula are cultural, contextual and theoretically based, aimed at creating music. Music curricula are often designed to fit a linear learning structure where progress can be documented.

Unlike many other subjects, music education also exists outside of the school environment.[87] Many children receive a musical education and develop their musicianship without an equal access to music in school. This may result in a divide in the classroom between those who have received tuition beyond the confines of the school and those that have not. Therefore, the kinds of musical knowledge and understanding that children are enabled to develop in Primary school and lower Secondary school music curricula should be considered.

Different conceptions of musical knowledge

There are various theoretical perspectives on what musical knowledge is. In the 1970s, Reimer[88] attempted to explain what musical knowledge was and categorise different types of musical knowledge. These were described as (i) an 'aesthetic' knowing *of* music in which we are aware of the feeling that music creates; (ii) a 'creative' knowing *how* to listen or create music; (iii) a 'theoretical' knowing *about* music through which we understand the theoretical concepts and notational forms that allow musical transmission; and (iv) a 'contextual' knowing through which we understand *why* music is as it is, within a cultural and socio-historical context of music. These different types of musical knowledge are not separate, but all are needed to develop musical understanding.

This theoretical perspective led to the development of curricula in North America and other countries based on 'aesthetic education'. This perspective attempted to explain music as a subject and to defend the inclusion of music curricula in schools.[89] It sought to demonstrate the unique nature of musical learning and knowledge. Consequently, many schools adopted this approach to musical learning. To some teachers however, it seemed to concentrate upon music listening, theory and history and did not account for the activity of performing music.

In the 1980s, Elliott[90] adopted a different perspective and defined musical knowledge in terms of how people play and listen to music. He argued that music is both a *form* of knowledge and a *source* of knowledge. Therefore as a *form* of knowledge, performers play with intention and do so knowingly. Thinking and acting are said to occur simultaneously and, as a result, performance is cognitive rather than mindless. The practical actions of the music maker illustrate their music knowledge.[91] As a *source* of knowledge, performance concerns communication and the performer is free to adapt their performance in order to communicate it, as this is socially lived. There will be a cultural history of the music (that may or my not be known) as well as social expectations. Both the performer and listener evaluate these and the listener will make sense of these through the musicianship of the performer. This theoretical perspective influenced the development of school curricula that were based on active music making and performing.

Swanwick has developed a contrasting theoretical perspective. This involves layers of musical experience that are centred around four ways of musical knowing.[92] These include (i) response to the properties of sound; (ii) perception of expressive characterisation; (iii) awareness of structure; and (iv) experience of meaning and personal value. For Swanwick, artificially extracting concepts such as rhythm, pitch, timbre, form, and creating a music curriculum based on these concepts does not allow for musical knowledge to be developed. He gives the example of teachers starting with a concept and then finding the music to fit it. These concepts have been *invented after the musical event.*[93] Swanwick proposes that music should rather be dealt with in a holistic way. He asserts that musical development does not occur in a linear way.[94] Furthermore, the emphasis of music making and creativity should be on musical fluency, the musical contribution of the child and the musical value and meanings that children create through acting musically. The emphasis in musical learning should not be on lists of competencies. This, for Swanwick, is not musical.

Summary

The evidence presented would suggest that:
- Musical knowledge and understanding must be rooted in music;
- All three philosophical perspectives on musical knowledge include music making as vital to developing musical understanding;
- Some perspectives value theoretical understanding more than other perspectives;
- Theoretical understanding should be integrated with practical understanding;
- Each of these perspectives advocates more than one type of music making;
- Cultural context is important in each perspective;
- The conception of musical knowledge and understanding will influence the way in which the music curriculum is developed;
- Philosophical notions of musical knowledge are what underpin music curricula.
- These can always be interpreted in different ways;
- None of these perspectives are based on psychological understandings of how the musical mind works.

What are the main curriculum activities?

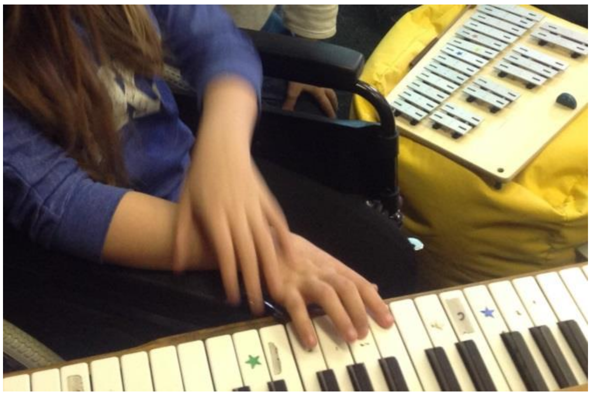
Music curricula for Primary and lower Secondary schools vary from country to country, but most encompass composition, performance and listening in some form. Within these broad areas, there are various ways that children can develop their musical knowledge and understanding.

Composition

Most compulsory music curricula contain composition and creativity in some form.[95] In particular, composition has been described as providing the key to musical understanding.[96] By creating music, children are believed to be able to explore the patterns, structures, transformations, and layers of a piece of music first hand. They can also develop a deep relationship with the expressive qualities that their own music produces. It is both a creative and aural experience.[97] Composition is an activity that is child-centred, and allows children to develop both fluency and meaning, and is seen to move away from *a skill-based, sequential curriculum*.[98] It is a way of extending children beyond their own initial musical experiences and towards sharing the musical values and traditions of others. Composition often encompasses arranging music[99], and includes the use of voice, instruments, body percussion, and technology.

Composition can occur in groups or individually. In the Primary and lower Secondary school, most composition is often carried out in small groups (or often pairs if I&CT resources are being used). Usually, children are given a stimulus, such as a painting, poem, or a narrative, and given a framework to compose within. This framework might include the suggested length of the piece of music, instruments/voices to be used, and structure of music. The stimulus may also be a different piece of music. Children might listen to a piece of music, discuss what they hear and be given a task based on something that arises as a result of the discussion.

As well as being a form of composition, improvisation has been identified as being the starting point for composition.[100] This often happens individually, even during group composition. Fautley's model for group composition identifies the different elements within the initial improvisation stage.[101] He refers to this as the 'pre-generative stage'. The process involves bringing together the musical knowledge, aesthetic awareness and repertoire of compositional techniques of the child(ren). The children both make and evaluate sounds after which they share their initial improvisations so as to generate further ideas. The model contains opportunities for children to develop different types of musical knowledge. A 'repertoire of compositional techniques' might involve *knowing how* to construct a composition. It might also involve *knowing about* the different symbolic ways of representing sound so as to fix it as a composition. 'Aesthetic awareness' may involve *knowing of* the fundamental feelings that their composition might generate, as proposed by Reimer (see above). Fautley's 'musical knowledge' could involve *knowing why* the children are composing to the particular brief that the teacher has set. It could mean knowing about music as a product.



Composition as part of a collective allows children to share cultural values and develop understanding of music through creative exploration. However, Fautley's model is based on the notion that children already have musical knowledge, aesthetic awareness, and a repertoire of compositional techniques. If they do not, the implication is that they need to be taught (inducted) in some way first. Therefore, by identifying the components of a potentially holistic activity, this can enable an understanding of the process, and the opportunity to map out linear or sequential learning as a result.

An important aspect of the compositional process is performing, evaluating and refining the composition. This is believed to enable children to develop a better understanding of performance. Fautley suggests that most children compose music that they are able to play themselves. Therefore, they can use the music as a form of knowledge, showing what they can do through performance. In evaluating their work, they are also using music as a source of knowledge.

Whilst this provides a good argument for the integration of composition, performance and evaluation (listening) activities it does not necessarily allow children to develop their performance skills beyond their current abilities. One solution is the use technology.[102] Another is the provision of opportunities for performance as separate activities to composition. By performing music composed by others (sometimes known as 'recreating' music), children can develop their own performance skills.

Performance

Performance can be whole-class, small group or individual. Many schools have a combination of different performance contexts. The purpose of whole-class performance in the classroom is to develop musical fluency.[103] Singing or playing together enables an individual to contribute to a fluent musical performance when individual difficulties might make solo performance less so. Through singing and playing together, children develop fluency alongside others. Many countries use singing to do this.

Historically, singing formed the basis of much musical activity before national curricula were introduced in the countries of the UK.[104] When the English National Curriculum in music was first developed in 1988, singing was not considered to be a central resource.[105] This was thought to have led to the decline of singing in Primary schools. Since the mid-2000s, however, the profile of singing in UK schools has been growing. This is largely due to the implementation and development of the National Singing Programme, known as Sing Up[106]. Other countries also place particular emphasis on singing. For example, research has found that it is the most common musical practice in Estonian schools.[107] Singing is also linked to musical movement in some countries, and many singing performances involve dance and movement. Nevertheless, where movement and dance is a specified part of the music curriculum in Spain, songs with actions are not considered to contribute to the dance/movement elements of the curriculum.[108]

Many curricula are founded on a tradition of singing traditional and/or religious songs.[109] Political agendas often contribute to the repertoire chosen in schools and have done since the 19th century.[110] Singing can, of course, cover a wide range of different musics. It affords the opportunity for children to explore different cultural singing practices, enhancing the development of their own musicianship.[111]

In reality, the songs chosen for class singing are a reflection of the teacher's knowledge of repertoire and musical genres. This may result in a narrow choice. Along with a lack of confidence amongst generalist Primary teachers in their own singing abilities,[112] some teachers do not have an understanding of children's vocal development. Comfortable singing ranges were mapped out as part of a longitudinal evaluation of children's singing for the UK National Singing Programme.[113] This demonstrated that the comfortable singing ranges of Primary-aged children are likely to be smaller and lower in pitch range than the range of many children's school songs, particularly for the youngest children. For teachers to be able to develop children's vocal performances successfully, they need to be able to choose repertoire that enables vocal development. This repertoire must start within the comfortable singing ranges of the children and gradually aim to extend this range with emphasis on good vocal health.

Effective singing pedagogy advocates children learning melody separately to words.[114] By so doing, children can explore the way the music is constructed so that they develop their understanding of musical patterns. Identifying musical patterns helps the internalisation and memorisation of the music. The internalisation of music enables children to develop an understanding of how to communicate the expressive qualities of the music as well as the lyrics in performance.

As well as featuring in composition, improvisation is evidenced as a performance practice in many curricula. Young children are observed improvising vocally as a form of musical exploration and expression when they are playing.[115] It is a natural and spontaneous behaviour. Moreover, instrumental and vocal curricula advocate the use of improvisation to enable children to explore playing techniques as well as develop their creative playing.[116] This in turn enables them to creatively interpret repertoire and enhances their musical communication during performance.

Instrumental performance is a less common musical practice than singing in the Primary school classroom. This is often attributed to the lack of specialisation of generalist Primary teachers. It is also attributed to lack of resources in schools.[117] Different interpretations of performing on musical instruments exist, and practices range from Orff-based instruments (such as xylophones), through 'found' instruments (as in the creative work of Stomp[118]) to standards Western orchestral instruments. In lower Secondary settings issues relating to resources (such as keyboards and I&CT) are often alleviated by the additional funds allocated to examination groups that require ready access to an appropriate range of musical instruments. In addition, music teachers in lower Secondary settings are almost exclusively music specialists.

To address issues of lack of resources within schools and inexperience of generalist Primary teachers in instrumental performance, the UK government introduced the Wider Opportunities programme in England. In much the same way as the Sing Up programme aimed to make every Primary school a singing school, this programme had the aim of providing every Primary school aged child with an extended opportunity to learn to play a musical instrument. The vision was that visiting specialist instrumental teachers would work alongside class teachers to provide an exciting music curriculum that enabled children to learn how to perform on a musical instrument. However, although effective in parts, the actual outcomes were somewhat patchy in terms of the quality of experience.

Most instrumental teaching taking place in schools in the UK takes the form of individual and small-group lessons given by peripatetic (visiting) teachers. A large number of children who learn an instrument in this way focus on the performance of staff notated music. They often work toward external graded performance qualifications such as those offered by exam boards like ABRSM[119] and Trinity College London[120]. Translating this into whole-class teaching has proved a challenge for teachers who had not worked in this way before. Moreover, many schools used their Wider Opportunities programme as their main curriculum music rather than as an enhancement to existing curriculum music provision. This has restricted the curriculum to just the activities associated with learning to play an instrument. Some examples of effective practice do include composition work, but many involve learning a single orchestral instrument (such as whole-class violin or whole-class clarinet) as a large group of up to thirty pupils.

The link between performance and music literacy is made in many curricula. Musical free play is used as a strategy for helping young children to understand musical structures, features (such as rhythms and pitch), and notations. [121] This involves improvisation and inventing notations. Often, invented notations are used to secure compositions to enable the performance of the composition, although they can also be used to measure musical understanding.[122] In terms of performance, '*notation is an intermediary for memorising, coding, storing and retrieving.*'[123]

Criticisms of teaching notation centre on the lack of musical experience with sound in the learning. Learning notation as an activity that is artificially separated from sound does not develop musical knowledge (see also the section on neuroscience in this review). However, understanding notation is important in *knowing about* music. Many of the criticisms refer to the *way* it is taught, rather than that it being taught at all. Many pedagogical methods successfully integrate learning notation into performance-based activities.[124] Notation is also a way of expressing musical understanding that is difficult to verbalise. Often when children listen to performances, they may show their understanding in their movements, but are unable to express their understanding. Notation can exist in many forms, and, as such, can allow children to represent the music that they have listened to in a form that enables them to demonstrate their understanding. For something to be represented, it must have been understood in some form in the first place.[125]

Listening

Listening can be part of both composition and performance, but it is often identified as a separate curriculum activity. Some countries, such as Jamaica, interpret listening as audience listening.[126] Often this means developing an historical understanding of the music being listened to.[127] An example of this can be seen in Finland where listening is linked to visits to concerts and learning music history along with theory.[128]

Studying music history has been widely criticised. In much the same way as teaching notation without reference to musical sound has been criticised, music history is criticised for being a study of the history of individual works. This leads to an unmusical approach, placing the emphasis instead on the biographies of the composers. However, thinking about music as history and developing an understanding of music's historical development, can enable children to develop a cultural and social understanding of music. All of the perspectives of musical knowledge that were previously explored place cultural and social context within the boundaries of musical knowledge.

Listening can provide opportunities for children to understand the way that music is constructed and the expressive qualities that different musical features produce. Analysing music through graphic notations allow children to develop an understanding of form and see patterns.[129] Graphic notations are a useful tool that enable children to make sense of the music that they are listening to. In turn, children are able to understand how to create a musical affect as well as build up a repertoire of techniques for developing their own compositions.

Notation

Notation runs throughout each of the three main activities of composing, performing and listening. It can do many things, including:

- measuring children's musical understanding;
- representing musical sounds;

- coding music so that it can be performed by someone else;
- acting as an aid for the memorisation of music so as to communicate musical meaning in performance and records musical thoughts or activities so that they can be developed at a later date.

This does not have to include traditional Western staff notation. Notations might be graphic, might be objects, might be physical movements or might be abstract (such as colours). Self-notation should be seen as a precursor to working in standard notation. Through notation/symbolisation we can see the musical and mathematical processes in the music. Moreover, we can see how these processes are the same in both music and mathematics. Through learning different notations, children can develop an understanding of how notations symbolise musical properties (sound) in the same way that mathematical properties are also symbolised in mathematical notation.

Summary

The evidence presented would suggest that:

- Composition mostly happens in groups;
- Individual improvisation is often the starting point for group composition;
- A stimulus is usually given to help children use their imagination;
- Composition requires the music to be fixed in some way;
- This might be through different kinds of notation;
- Composition allows children to develop different kinds of musical knowledge;
- Composition allows children to demonstrate their musical understanding;
- Performance and listening skills are needed for composition;
- Performance as a stand-alone activity enables children to move beyond their current capabilities;
- Singing is the most common performance activity;
- Instrumental performance activities may depend on resources in school;
- Moving beyond rote learning allows children to develop understanding of notations;
- Different pedagogical methods integrate notations into performance activities so that understanding of sound and symbol are developed holistically;
- Understanding notations allows children to code, internalise, store and memorise music;
- Notations also allow children to demonstrate musical understanding in a non-verbal way;
- Listening activities often include developing historical and theoretical understanding;
- Children can represent music that they have listened to in many different forms.

Overall, the different sections of this literature review are designed to demonstrate that both music and mathematics in the Primary and lower Secondary school are both accessible and inclusive and that it is possible to support children's mathematical development by engaging in music. Children will develop their mathematical understanding by education *in* music and education *through* music.

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[61] Note that in the recent official documentation (unlike previous versions) there is no guidance as to 'who' the great composers or musicians might be, enabling, with best practice, teachers to define 'great' in relation to the needs, interests and context of their pupils.
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[63]For further details of the revised English National Curriculum for Music see https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/239037/PRIMARY_national_curriculum_-_Music.pdf [last accessed 13.03.2015]
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/239088/SECONDARY_national_curriculum_-_Music.pdf [last accessed 13.03.2015].
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