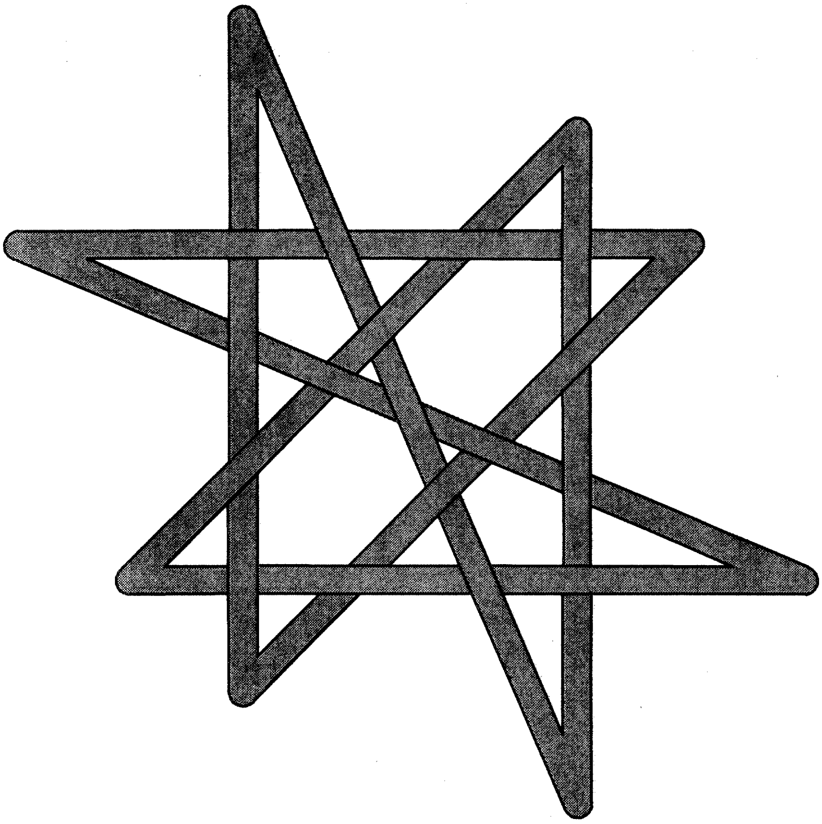
Spatial Ability:
A Handbook for Teachers



Edited by
Tandi Clausen-May
and
Pauline Smith

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Contents

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Foreword

This handbook is concerned with 'spatial ability': what it is, why it is important and how it can be developed. Our aim is to offer teachers some of the knowledge, understanding and teaching techniques needed to enable them to provide a balanced curriculum for all their pupils and particular help for those who have stronger spatial than linguistic ability.

A major problem throughout the history of research in this area has been that of defining exactly what is meant by 'spatial ability'. In order that readers may be attuned from the outset to the way in which the term is employed in the handbook, we will start with a working definition.

> *Spatial ability – a collective term for a wide range of acquired skills, all of which make use of basic memory for shape and position.*

Several key points concerning our conception of spatial ability can be inferred from this definition. Since spatial ability is used as a general term to cover many different kinds of skills, there is no one test that can be said to measure overall spatial ability – only different tests to measure different spatial skills. People will appear to have stronger or weaker spatial ability depending upon the particular spatial skills that are chosen as indicators of that ability. For example, someone who does well on a test of interpreting engineering diagrams may be less outstanding when interpreting dressmaking patterns. But although evidence of spatial ability can be obtained only by observing acquired spatial skills, we cannot assume that spatial ability differences are due solely to differences in learning experience. Two people may have the same experience of dressmaking patterns, for example, but one may still be better than the other at interpreting them. All spatial skills make use of *basic memory for shape and position*; there is now considerable research evidence to indicate that the potential to acquire various spatial skills (sometimes termed 'spatial aptitude') depends upon the strength of a person's basic spatial memory (Carpenter and Just, 1986; Lohman, 1988). This can affect the ease with which the skills are acquired and the ultimate level of skill achieved.

Another point to bear in mind is that spatial ability is not positively related to linguistic ability. In this handbook, *linguistic ability* refers to a range of acquired skills which rely on *sound-based memory processes*. Pupils with good spatial ability may or may not have comparable linguistic skills. This being the case, it is not possible to assess a person's spatial aptitude from a test which requires linguistic processing, any more than one could assess his or her linguistic aptitude from scores on a spatial test. The implications for the education system of this independence of linguistic and spatial abilities are far-reaching. At present, educators rely heavily upon linguistic assessments, formal and informal, as indicators of overall intellectual potential. Children with poor linguistic ability who exhibit signs of good spatial ability are frequently described as 'slow, but with an artistic gift' or 'not bright, but good with their hands'. In contrast, it is rare to hear children described as 'slow, but with a linguistic gift' or 'not bright, but good talkers'.

So the educational progress of pupils with marked spatial strength may be further hampered by low teacher expectations, particularly if these are coupled with a dispiriting remedial emphasis upon their verbal weaknesses. The heavy reliance of the formal educational system upon verbal and written forms of communication leaves such pupils struggling even in 'spatial' subjects. Although they may display clear signs of their spatial aptitude, with excellent drawing skills, a talent for making models, or an interest in mechanical objects, they are likely to be considered less intelligent than other pupils who are more skilled with words – pupils who are less good at making drawings or models, or working with machines, but who can read, write and talk more fluently about them. Children, even more than adults, may vary in the extent to which words play a part in their reflective thinking and problem-solving strategies. The danger is when 'verbal' educators try to force their own approach inappropriately on 'visual' children.

The overriding aims of this handbook are to help teachers to understand the significance of spatial ability, and to encourage them to give it parity of esteem with linguistic ability, seeking to identify and nurture it in their pupils. To this end, the handbook starts with a discussion of some of the problems which face spatial thinkers in our education system. It then goes on to offer some examples of ways in which teachers can develop the spatial abilities of all their pupils.

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Introduction

Education and Spatial Thinkers: Examples Past and Present

The tendency of teachers and educationists to underestimate the potential of spatially gifted children is not confined to recent times: it has been going on for centuries. Evidence for this can be traced through biographical material, and from autobiographical accounts given by people who have ultimately proved to be talented in one or more spatial pursuits. It may be argued that educational blunders are bound to occur, and are not confined to those with potential for spatial careers: some literary giants were informed as children that they had no talent for writing. However, the prevalence of 'school failure' among those in spatial careers, together with the dominance of language-based work in most school curricula, past and present, suggest that spatially biased children could form a particularly disadvantaged group.

Of course, no one would argue that having strong spatial abilities *necessarily* leads to poor educational performance. There are the enviable all-rounders, possessed of strengths in both spatial and linguistic thinking, who will always do well provided they are motivated to do so. But our concern here is with those whose spatial powers exceed their linguistic ones: they are the people who have floundered educationally and who will continue to do so. If, as seems to be the case, spatial and linguistic abilities are largely independent, then there will be many such cases.

In his 1964 book, Ian MacFarlane Smith presented much interesting biographical material concerning eminent spatial thinkers from the past (Smith, I. MacFarlane). His notes refer to the poor linguistic skills of such well-established figures as Richard Trevithick, Thomas Edison and Albert Einstein: the records of their early lives show how spatially gifted children may be regarded as intellectually slow when they are judged by their ability to express themselves. In fact, MacFarlane Smith believed that, rather than being independent, spatial and linguistic abilities were to some extent opposed, with the consequence that the spatially gifted would be more likely than average to have poor linguistic abilities and vice versa. This belief has intrinsic appeal, and most readers will be able to produce their own anecdotal evidence to support it: the incoherent mathematician, the expert speaker who cannot master the use of an OHP, and so on. However, it cannot be assumed that such discrepancies in adulthood or even in later school days result purely from differences in aptitude. Given the chance, people will often concentrate on those things they do best; as a result, very slight initial discrepancies will become gradually more marked, as the result of practising the strengths and neglecting the weaknesses. The early specialisation that prevailed in English secondary schools prior to the National Curriculum may have been an example of this tendency in action. The 13-year-old with some talent for language work would drop science, art, geography, craft and, if at all possible, mathematics; whereas her classmate with spatial strengths would abandon English literature, history, foreign languages and, if possible, English language.

MacFarlane Smith also reviewed substantial evidence that the intellectual differences were matched by characteristic personality types. That is, spatial thinkers tend, on the whole, to be shy, socially withdrawn introverts, in contrast with the more gregarious, extroverted linguistic thinkers. These differences in character and style of behaviour might themselves tend to exacerbate the discrepancies in intellectual development: the shy, socially inept spatial thinker is less likely to develop good linguistic skills, while the gregarious, outgoing linguistic thinker may have less opportunity to work with machinery, maps, and so on. More recently, the psychologist Howard Gardner has distinguished between two extreme types in childhood, in terms of their play preferences. He refers to ‘patterners’ and ‘dramatists’, in accordance with the children’s preference for either constructional/design toys or for social role-playing. This distinction could well correlate with the eventual development of spatial and linguistic thinkers (Gardner, 1980).

Whatever the cause, many people show marked discrepancies between their spatial and their linguistic aptitudes. Furthermore, history shows that children with exceptionally strong spatial abilities and relatively weak linguistic abilities are likely to suffer at the hands of their teachers. MacFarlane Smith quotes the example of Richard Trevithick (1771 - 1833), who at the age of 30 designed the first steam engine ever to draw a passenger vehicle. He was a solitary child, who preferred drawing to doing school work: he was described by his teacher as 'disobedient, slow, obstinate, inattentive and a frequent truant'. Thomas Edison (1847 - 1931), the inventor of electric light, fared no better: he was expelled from school at the age of seven, having been labelled 'retarded' by his teacher. And most notable of all, perhaps, Albert Einstein (1879 - 1955) gave serious cause for concern. He was so slow in learning to speak that his parents feared he was subnormal. He left school at the age of 15 with no diploma – but fortunately he was not written off by his family. His uncles encouraged him to take an interest in mathematics and science, and he resumed his education in Switzerland, studying physics for four years at the Zurich Polytechnic Academy. He eventually established his reputation as the genius of the century with his theory of relativity. He knew himself to be a spatial thinker: he explained that words and language played no role in his original thinking, which was visual or movement-based, and that linguistic descriptions of his ideas had to be sought afterwards, laboriously.

What, then, would twentieth-century educators have made of these cases? What labels would have been put upon them? Sadly, there is no shortage of clues to help in answering these questions: spatially gifted people have continued to experience educational difficulties up to the present day. Many examples, solicited and unsolicited, have been brought to our attention during the course of the research underpinning this handbook. They range from detailed accounts to brief comments, but they share certain key features. All of them concern individuals who have exhibited a high level of aptitude for spatial thinking, either through career success or, in the case of the younger contributors, through formal or informal assessments. All of these cases involve people who have experienced some degree of dissatisfaction with their education, ranging from those for whom school-days were a living nightmare to those who merely felt that they had been 'short-changed' by their schooling, in that their spatial thinking potential was never recognised or developed, even if they did very well academically.

Focusing our attention on the experiences of children in school today, we may identify three broadly defined groups who are likely to encounter serious educational difficulties while showing evidence of relative strengths in spatial thinking. These groups may be considered separately, but in reality there is a lot of overlap between them. A detailed discussion is beyond the scope of this handbook, but a brief outline may be useful as, between them, the groups cover a significant proportion of those children who have a bias towards spatial rather than linguistic thinking and learning.

The group whose spatial strengths have been most thoroughly assessed are those children who are described as dyslexic or as having specific learning difficulties (SpLD). Very often, such children have great difficulty learning to read and spell despite having average or above-average scores on 'IQ' tests. When these scores are broken down into scores on different types of sub-test, many of these children show marked strengths in tasks that use visual material such as objects, designs, and pictures, in contrast with a weakness in tasks requiring a sound-based memory for sequences of words or numbers. While such children generally have a good understanding of language, they do give other indications of linguistic difficulties. For example, many of them are slow in learning to speak and some require help in learning to pronounce words correctly. They frequently have poor memories for information given to them aurally, so that instructions have to be broken down into small steps and repeated. Finally, some of these children also have difficulties in doing mental arithmetic, if the questions are presented aurally with no visual stimulus. Such children have poor short-term memory for sequences of sounds, in this case numbers and operations.

Taken together, these characteristics of dyslexic children do seem to have much in common with our case studies of spatially talented people. Sometimes, dyslexia is diagnosed – although this diagnosis may come too late. For example, Martin, a graduate in materials technology in his 30s, contacted us in the course of our research. Martin struggled all through his formal education, but it was not until initially failing his finals at university that he was assessed by an educational psychologist and found to be 'quite severely dyslexic' with a Wechsler IQ of 138 and 'extremely good spatial ability'. As Martin explained:

> *The current teaching styles do not take account of this and students like myself find that we continually underachieve purely because we are*

> *unable to demonstrate our full ability. Current teaching methods have both stifled me and destroyed my confidence in my own intellect.*

Martin eventually completed his degree after several extra years 'battling his way through the education system' – but many other dyslexic adults have gone unrecognised, and have been overwhelmed by the odds stacked against them.

Martin's dyslexia was diagnosed when he had already spent many years in the education 'battle'. Now, perhaps, young people with good spatial aptitude but markedly poor linguistic skills are more likely to be identified as being dyslexic while they are still at school. If this leads to their being offered effective remedial help and frees them from the suspicion of being lazy or stupid, then it is clearly beneficial. Martin could have had a much happier educational experience if his dyslexia had been identified earlier. On the other hand, if identification of dyslexia is not followed by appropriate remedial help, designed to exploit the child's strengths rather than emphasising their weaknesses, then it may just lead to a lowering of expectations for the child and be of little benefit. None the less, the label 'dyslexia' does at least provide some sort of explanation for an otherwise puzzling and distressing condition. Such a diagnosis highlights that the child's difficulties are indeed specific, and that they are balanced by relative strengths in spatial thinking. Such strengths may otherwise go undetected, or be dismissed as isolated practical (and by implication, non-intellectual) abilities for drawing or model making.

Susan, a 12-year-old who was receiving special help as she could not read or write, provides an example of a pupil whose weaknesses were identified, but whose strengths had been consistently overlooked. As an 'extra', to make a change from her usual diet of 'remedial' reading and writing practice, her teacher introduced a unit of study on the history and origin of the alphabet. Much to the teacher's surprise, Susan was able to remember and draw 'a marvellous copy' of an old, complex Chinese character. As the teacher explained:

> *Susan's ability to take a complex figure, break it down into chunks and then recreate it nearly perfectly indicated that this pupil had more*

> *strengths than most people had recognised or taken advantage of for most of her years at school.*

Susan was not identified as being dyslexic – but the criteria for identifying or defining dyslexia are notoriously variable. Furthermore, two commonly applied criteria may reduce the likelihood that some children with spatial strengths but linguistic weaknesses will be categorised as having dyslexia. If a child is emotionally or behaviourally disturbed, or if they come from a deprived background, then it is likely that any failure they may show in acquiring linguistic and reading skills will be attributed to these causes and not to dyslexia. Clearly, it is reasonable to suggest that a child's learning difficulties may result primarily from their emotional or behavioural disturbance, or from a lack of educational opportunity. However, it could also be the case that some disturbed or deprived children also have those linguistic weaknesses and relative strengths in spatial ability which are associated with dyslexia. Indeed, learning difficulties may themselves contribute to emotional disturbance. Furthermore, social deprivation and illiteracy, like dyslexia, run in families: it is at least possible that undetected dyslexia in successive generations is contributing to the long-term educational and social problems found in some families.

Thus we can identify the second broad grouping of children who may well include a substantial number of spatial thinkers. These are children who experience difficulty in acquiring 'the three Rs', and who also come from a deprived background or show serious emotional or behavioural disturbance. The evidence for spatial bias among this group is more anecdotal and circumstantial than that for the group of pupils identified as dyslexic, but is none the less worth noting. Many pupils in special schools for emotionally and behaviourally disturbed children show surprising spatial ability, and respond with quite uncharacteristic enthusiasm and concentration when offered non-written, spatial tasks.

So far we have identified two broad groups of children: those who are dyslexic and those who show emotional or behavioural disturbance or come from deprived backgrounds and fail to learn to read. Both of these groups involve children who may have good spatial ability but have relatively poor verbal and linguistic skills. But as we have already observed, children whose high spatial ability is balanced by adequate linguistic strengths will, if motivated, achieve well at school. This brings us to the third and final broad grouping of children with good spatial aptitude: namely, those with sufficient linguistic ability to manage in the education system, and to overcome the difficulties it may present. Two cases illustrate this well.

John, aged 52, is a successful Drawing Office manager. His father was a naval architect and his mother a talented needlewoman, so, as John explains: 'There was plenty of spatial activity around the house.' John was sent to a private preparatory school and had individual tuition in English prior to passing the entrance examination to a selective grammar school at the age of 11. He describes himself as having been 'shy and introverted' at school. His abilities and preferences for school subject areas showed a clear split along spatial/linguistic lines: he liked and did well in anything practical or visual (sport, woodwork, drawing diagrams, geometry), but disliked and had less success with subjects that required linguistic thinking and rote memory (history, foreign languages, chemistry, algebra). The only exception was English language where, despite difficulties in understanding grammar, punctuation, and spelling, he enjoyed and did well in essay-writing. In contrast, he comments that he had and still has great difficulty in 'thinking on his feet' and expressing himself in conversation. As he explains, he 'thinks of some excellent things to say but immediately forgets them again if he doesn't write them down'. Words, unlike shapes, pictures or patterns, slip away from his short-term memory almost as soon as they come to mind.

After leaving school, John obtained a position as an apprentice draughtsman and has pursued that career ever since. He feels that it would have been beneficial if his strengths and weaknesses had been better identified and addressed at school. In particular, as a young man he took an HNC course in engineering; but he eventually had to abandon it owing to his weakness in algebra. This went unrecognised at school – or at least, was not seen as a serious problem, because his relative strength with more spatial aspects of mathematics meant that he came out overall as a good, above-average mathematician.

Another adult spatial thinker who survived the linguistic demands of formal education, and eventually entered a career in which his strengths could be exploited effectively, is Lt.-Com. Simon Burns, a navigation officer in the Royal Navy. He read about the research being undertaken for this handbook in an issue of *Navigation News*, and wrote to us with an account of his experiences.

The Lt.-Com. was a late talker, beginning to speak only when he was four years old. Educated at a 'traditional Scottish public school', he was brought up as 'an intellectual and a linguist'. He reports that:

> *School did nothing for me spatially. Although I knew I was not stupid, I did not realise my IQ until I joined MENSA. Since then I have come to understand that not everyone sees things the same way as me, or thinks in the same way.*

For example, he writes:

> *A chance question from a friend of a friend caused me to admit what I had never previously admitted to anyone (for obvious reasons), namely that I have always had, and continue to have, difficulty in applying East and West correctly. This for a professional navigator is rather like a vicar admitting he is a Satanist! However, if directions are described in degrees 0 to 360, as is the custom in navigation nowadays, I have no problem. It is only those two words and directions I hang up on.*

In order to study effectively for professional qualifications – which, in common with virtually all formal qualifications in our education system, relied heavily on written assessments – the Lt.-Com. developed his own 'network style' of taking notes and 'laying things out on paper'. He writes:

> *This is infinitely more effective in helping me to learn, and I find it is easier to recall in exams. The drawback is that it is not easy to explain or give to other people, because it is so far removed from their way of traditional linear writing and thinking. The problem is that it is a*

> *minority approach, and so much of the world is organised in the linear style of the printed page.*

So, *why* do some very bright children have so much difficulty communicating with their teachers that they come across as quite the opposite of 'bright'? How could it happen that Einstein – Einstein of all people! – left school with no formal qualifications at all?

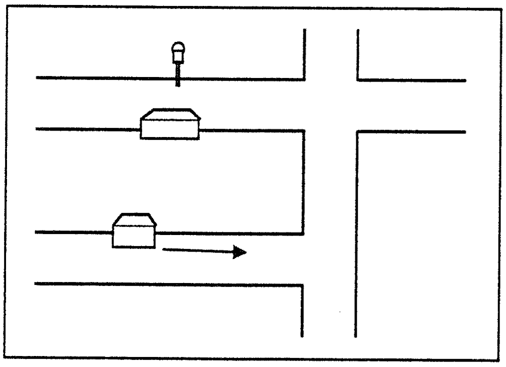
One part of the answer may lie in the difference between the way in which the two sides of the human brain work. As Grayson Wheatley *et al.* explain:

> *the two hemispheres of the cerebral cortex process stimuli differently... The left hemisphere treats stimuli serially, one at a time, whereas the right hemisphere processes stimuli many at a time as a gestalt* (Wheatley *et al.*, 1978)

To give a very simple example, someone who is using the left hemisphere might give directions serially, like this:

> *Go to the T-junction at the end of this road and turn left. Then take the next left. The house you want is on the same pavement, opposite the lamp post.*

On the other hand, a right hemisphere 'gestalt', giving a complete, overall picture, might look more like this:



Like other spatial thinkers, Lt.-Com. Burns thinks predominantly with the right side of his brain: in Wheatley's terms, he 'processes stimuli many at a time as a gestalt'. This gives him a great advantage with some types of task, but hinders him in others. As Wheatley *et al.* go on to explain:

> *This functional difference* [between the two sides of the brain] *renders each hemisphere superior in performing certain types of tasks; the left hemisphere is better at such tasks as reading, speaking, analytical reasoning, and arithmetic, and the right hemisphere is better at spatial tasks, recognising faces, and music (*Wheatley *et al.*, op. cit.).

This is what Lt.-Com. Burns meant when he wrote: 'Not everyone sees things the same way as me, or thinks in the same way.' He recognised that his was 'a minority approach, and so much of the world is organised in the linear style of the printed page'.

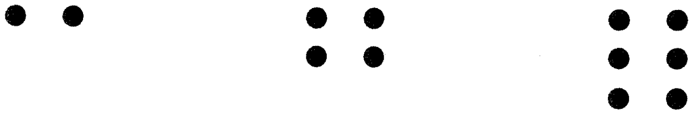
It is a cliché that the invention of writing, and then of printing, has had a great impact upon our culture and our educational system. Within the English curriculum, for example, what is studied is the written text of a play. The pupils' level of achievement depends upon their knowledge of the text, and their ability to write about it – not upon their ability to direct or perform in the play. Again, a pupil may be asked in a science test to describe the theory underlying the structure of an electrical circuit, but she is less likely to be asked to change a fuse. And in mathematics, the purely symbolic representation:

$$2 \times 1 = 2$$

$$2 \times 2 = 4$$

$$2 \times 3 = 6$$

is regarded as the 'correct' way to express the two times table. On the other hand, the graphical representation:



is seen as intrinsically inferior: it is 'only a picture', although it actually tells us far more about the mathematical structure which underlies the string of numbers and operations which are represented by the chanted 'two ones are two; two twos are four; two threes are six'.

So the printed page, with its linear, two-dimensional, static means of communication, favours the left hemisphere of the brain. This is the mode of communication which predominates in every area of the school curriculum. The system is self-perpetuating, as only those people who are able to perform at least adequately on such left hemisphere tasks as reading, speaking, analytical reasoning and arithmetic are likely to do well enough to become teachers, while those for whom the right hemisphere dominates may, like John and Lt.-Com. Burns, find their way into careers in which their spatial abilities serve them well, but they are unlikely to become teachers.

Virtually everyone has some ability to think spatially, just as everyone has some ability to think linguistically. A person could not function anything like normally without using both sides of the brain to some degree. The differences are in the balance, in the relative strength of the two modes of thought. But both ways of thinking can be greatly enhanced by appropriate teaching. The problem lies in our education system, which emphasises the linguistic and symbolic out of all proportion. In doing this, we clearly fail to meet the needs of pupils who are predominantly spatial thinkers – but we also limit the learning of pupils who could, given the opportunity, develop their spatial mode of thought as well as the linguistic mode they more generally use in response to our book-based curriculum.

The rest of this handbook offers a range of ideas from teachers working with pupils of different ages in different subject areas. The reader may want to select ideas and situations which suit their own circumstances – and then adapt and develop the activities and approaches described. Each of the suggestions is intended to offer starting points for teachers to take forward in many different ways.

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Chapter 1

Construction Work in Schools

In this very practical guide to construction work, ***Trevor Aldous*** *suggests ways in which a wide range of materials, including both 'junk' and commercial kits, may be used with pupils of all ages. The focus of this work may be within the technology curriculum, but it may also be seen as complementing other aspects of the primary or secondary curriculum. The sections on 'Organisation', 'Recording and Presenting' and 'Parents and Visitors' are relevant for pupils of all ages and levels of achievement; other sections offer a range of activities, and advice on materials and commercially available kits, from which a teacher may select those which are most appropriate to their particular situation.*

1. The Importance of Construction Work

Building is a natural activity for us all. We are born into a three-dimensional world and there is a basic need to interpret this world through drawing and making. Children will already be moulding sand, stacking bricks and arranging boxes at an early age. By creating a stimulating environment at school and providing a wide range of constructional materials, we can reinforce these early discoveries, accommodating developing skills and changing interests.

Girls should be given plenty of opportunity and positive encouragement to develop their 3-D skills. Schools often reap the boy-orientated heritage of Meccano and Lego. Most boys like construction work and may be quite skilful simply because they have their own kits at home. Girls may have little more than a few pieces of basic Lego 'belonging to' or 'handed down from' a brother and, when they have not had early infant experience of this, they may not see it as an activity relevant to them. Schools can play an important compensatory role here, helping to redress the balance.

Making is often an organic process where, instead of designing to make, we solve problems of design as we use the materials to hand in the best possible way. In today's society we are becoming increasingly divorced from the making process.

However, at school we can nurture the child's early interest, so that their development in making things work well runs parallel with the aesthetic awareness of artefacts looking and feeling good.

2. Starting with Junk Materials

Junk modelling is important for its constructional and creative implications and therefore complements both art and technology within the curriculum. Young children will develop skills of cutting out neatly, folding and rolling up. When making models, there will be many opportunities for being skilful at placing, fixing, joining and painting: using scissors, glues, fasteners and string to make tabs, flaps and hinges. Here the child will begin to recognise that alternative ways of joining materials are needed if their initial choice is unsuccessful. Boxes can be opened up and the method of construction examined. These skills will be the key to the realisation of models that show imagination and inventiveness. Older children will benefit from looking at the work of artists who recycle materials.

Common domestic waste materials such as cereal boxes, and tea and coffee packaging are excellent for sorting and shape work as well as making models. Child-size cardboard boxes make wonderful houses, cages, holes: build on this basic need of the young child to curl up in an enclosed space.

Card, wood, brick, plastic, wire – all these may be used to help children to understand tactile qualities and characteristics of resistant materials. Polythene piping, bricks, pebbles and timber can be gainfully incorporated in large-scale maze making, pattern and shape work in hall, playground and field, giving children an awareness of the sense of space.

The glue gun is a useful implement when translating a concept to finished construction, bypassing a frustrating wait for the glue to dry. Finished models can be painted and decorated. The child will need to experiment with paint and surfaces: for example, will ordinary ready-mix paint 'take' on the shiny surface of a cereal packet? If not, how can she overcome this? As children get older they learn about the appropriate use of materials and acquire the extra strength which enables them to use sophisticated tools to cut and shape.

Schools may wish to develop a craft/technology storage area (e.g. in a shared practical area) where cutting tools, scissors and card snips, glue gun and PVA glues are safely accessible. A variety of strings, tapes, labels, paper clips and fasteners is also essential.

3. Commercial Kits

Commercially produced construction kits are available in various shapes, sizes and degrees of sophistication. Although manufacturers often state an age suitability, it is unnecessary to hold rigidly to this. Children in key stage 2 as well as those in key stage 1 can use Mobilo, Sticklebricks and wooden blocks as part of an overall environment. All too often the younger children are given Mobilo and Duplo, those in the middle year groups may have Lasy and Lego, and only the oldest pupils in the school have Lego Technic and kits with motors. But as the child moves through the school, it is the sophistication of the activity that can change and not necessarily the kits themselves. Most kits can be shared by all ages. Depending upon the financial constraints, it may be better to choose a small number of commercial kits and concentrate on building up a good supply of pieces from these, rather than obtaining a few pieces from a large number of incompatible kits.

Types of Kit

Kits may be divided into four main categories, according to the method of assembly they employ.

1. Simple systems of interlocking blocks:
e.g. Lego, Duplo, Lasy, GeoBlock, Multi-Link.

2. Open frameworks that introduce joints:
e.g. Mobilo, Pipeworks, Reo-click, Quadro, Tactic, Construx, Lego-Technic, Junior 200, K'Nex, Lego Dacta Structures Activity Pack (for bridges and towers).

3. Systems that require the use of nuts, bolts and tools:
e.g. Bauplay, Brio-Mec, Meccano.

4. Motorised systems:

e.g. K'Nex Power Sets (battery, spring and mains power), Motor Lasy, Construx, Meccano, Lego Dacta Powered Mechanisms, Lego-technic.

All the above have wheels and some have pulleys and other accessories. Specific cogs and gear sets include Start Gear, Lego Dacta Fun Time Gears, and Gear Go.

Some commonly used kits are described in more detail below.

Mobilo: Tough, brightly coloured polythene in smooth moulded open shapes: panels, wedges, cubes, cuboids, wheels. These are clipped together with simple multi-joints. Excellent for very young children from playgroup onwards.

Pipeworks: Large white polypropylene pipes with colour-coded joints fixed by a sprung push-lock device, similar to that used in vacuum cleaner rods. There are panels and wheels. They are versatile and build into large open structures that can be used to create shops, tables, chairs, slides, and so on.

Quadro: Similar to above, with locking studs rather than sprung locks.

Lasy: Brightly coloured system of tessellating A and H blocks with base plates, axles, and wheels. Components of various sizes – all compatible. Very sturdy and easy to manipulate. As each piece fits to make integral hinges, it can build at varying angles. Particularly enjoyable at all levels and ages. Constructions can mushroom and allow greater scope for interpretation than Lego. There is a compatible motor set.

Bauplay: Large, tough, egg box-size blocks of varying shape fixed with colour-coded nuts and bolts. There are wheels, cog wheels, laths and tracks. Large models can be used and even sat on. One of the more expensive kits, which can be used throughout the primary school and beyond. (Note: Bauplay is used by apprentice engineers in a leading British car manufacturer.)

4. Organisation

Time and space need to be planned with a flexible framework which provides children with the opportunity to work as individuals and in mixed age and ability groups.
When we think of organising the environment, it is important to consider how various

kits and other materials are used throughout the school. A hall or practical area may be more suited for large-scale work with Pipeworks, Tactic, wooden blocks and bricks. Children will benefit from this freedom of space.

Defining a space acts as a way of setting limits and focusing on the making process. In the hall, large foam PE mats are excellent for the purpose, as they map out a generous space in which to work and can be pulled to the side if extra room is required. Four large sheets of sugar paper will serve the same need. In the classroom, both carpeted and tiled areas as well as tables are very useful. Carpets create comfortable working environments and both carpet and tiled areas aid the testing of wheeled and motorised models (especially for friction). Individual carpet squares are useful for small constructions.

Depending on the clemency of the weather, playground and patio can be used for large structures and for estimating, testing, then recording speeds, distances and sizes. When compared with the surrounding grounds and school buildings, the models will take on an extra dimension. The child will have more room to observe large models from different angles.

Some clearly defined areas for storage are necessary. Large equipment can share a space in the hall with PE apparatus and this move will better facilitate equal sharing of equipment throughout the school. Multi-drawered storage units are excellent for the smaller pieces like Sticklebricks, Mobilo and Multi-Link. To facilitate both storage and movement around the school, a shelved trolley with stacked boxes would be useful.

A wise move would be to decant kits from the flimsier manufacturers' boxes. Separate boxes and tubs can be used for storing fitments such as wheels, joints and clips. Cheap plastic or, preferably, polythene boxes and trays can be obtained from supermarkets and garages and many are free.

Label everything clearly, using pictorial symbols as well as words for children who cannot read well. This will help to ensure that everyone knows where each kit and component is stored and how to replace it correctly. This activity has spatial relevance when children have to reach up or down, on top or under, fit stacked boxes together, place blocks in their correct pattern or sequence (for example, wooden community bricks), and sort out colour-coded components.

5. Activities

Children need to be given time to explore and familiarise themselves with new kits and materials. (Children who do not have kits at home will find this particularly beneficial.) For younger children, this involves both sorting activities for colour, shape, size and number, and matching, rotating and positioning individual pieces. Encourage early classification of pieces by colour, type and function. These activities will help develop memory, mental rotation and manipulation skills. This is the time when children can develop a 'mental ruler', so acquiring long-term representations of standard lengths.

Simple tasks that invite exploration and prediction can develop from initial play, for example 'Is the model strong and steady?' 'Can it move?' Further development can come where challenges allow individual interpretation, for example using a mixture of materials to build a castle with a moat. Later, children can build models to perform specific tasks and introduce various forms of movement. They explore a range of ways of joining, and become accurate at fixing objects securely.

At times, children will be required to follow written and oral instructions and give instructions to others. Manufacturers' instruction sheets and work cards do play a part but can be difficult to follow and are often limiting. It is a worthwhile activity to encourage groups and individuals to design their own instruction sheets and work books. Gradually a collection can be built up, some pieces being covered with plastic and used by future groups.

As most kits have collective names only, children may invent their own names for particular pieces, for example *fixer* or *sticker* for a three-way joint; *telephone box* for a Mobilo block. Furthermore, the need to explain the processes they are involved in naturally extends their vocabulary and spoken language.

Making structures of different sizes will involve reorientation where the child can move around, climb inside and position smaller objects within a framework.

Educational work that aims to develop such visualisation skills has been carried out by architects (see Celia Clark, in Chapter 2 of this handbook).

Many problems of construction are solved within the context of the child's own realm of play and fantasy. Therefore it is important that time for further imaginative play is given, allowing for the child's natural curiosity and tendency to gather found objects such as feathers, sticks, pebbles, and so on.

We all need to see and touch real artefacts if we are to have any understanding of their construction and of the materials used. Young children need little encouragement to bring in their toys and models from home so this can be an easy starting point. Spend some time on investigation: can they see how their toys/models are constructed and how they work? Make a collection of objects that have a common attribute and see if the children can recognise the similarities. You could start with wheels or hinges. Look at the inside of a clockwork toy and make a collection of springs and cogs from broken clocks and other mechanical devices for work on cogs and gears. Make these with card lids and corrugated paper, simple plastic cog sets, Bauplay or motor Lasy.

Construction work naturally falls within the technology curriculum but it should also be seen as complementing all aspects of the curriculum. Making may be initiated from familiar traditional stories, for example towers and the castle from *Rapunzel*; bricks, tiles, pebbles and wood for the maze in *Theseus and the Minotaur*; straw, sticks and bricks for houses in *The Three Little Pigs*; and animals and the bridge from *The Three Billy Goats Gruff*. The children's own fantasies can equally well serve as a starting point.

A visit to a building site could fall nicely into a variety of topics: houses, rooms, town or village, structures, diggers and so on. There are obvious opportunities here to complement other curriculum areas. A building site environment can be created using a variety of constructional materials and PE benches, ramps and wedges. Make a collection of building materials which you can add to your resources for future work.

Young children can observe and reproduce patterns in stone, brick and roofing tiles. In movement, they can pump their arms like diggers and compare elbow action to the hydraulic digger arm. This action can be translated using card and paper fasteners, kits and waste materials.

Older children would look at mechanisms and the characteristics of resistant materials and make measurements using standard and non-standard units. Mini-quadro, Lasy and various resistant materials could be used as prototypes for larger buildings and vehicles, helping them to develop a sense of scale.

Making days that involve the class, whole school or visiting classes from neighbouring schools will help reinforce the importance of this work. The day may fall within a technology/design/construction week at the school(s). Sharing equipment and knowledge is both practically advantageous and socially rewarding.

6. Recording and Presenting

Information can best be presented using a variety of graphical and written forms, for example children may make step-by-step diagrams, drawings, instruction sheets, plans, graphs, written accounts and imaginative stories. Plans will not necessarily precede making: young children will be happier drawing a finished model and will be confident in making a simple preliminary plan only when they are expert in handling their material. Simple plans can start with the child drawing round wooden blocks when making a room. This can be developed by drawing round a model of a street, built on a sheet of paper, which reveals a map of the street when the model is removed. Children will find it easier to interpret or 'read' a 2-D graphic representation of a 3-D construction (e.g. know that some parts are out of view) if they have had early experience in drawing simple side and front elevations of their models. Pupils in key stage 2 enjoy 'activity sheets' which combine pictorial representations of the materials used and chronological steps in making.

Allow time for sharing and presenting work to others. Here pupils working at different levels can take pride in their work and share their achievements, describing the problems encountered and modifications made. Also an assessment of particular kits and their suitability for different activities can be discussed at this time.

7. Parents and Other Visitors

Displays will often be a parent's first contact with construction work. However, to reinforce understanding of the variety of 3-D work in schools, it is a positive step to hold construction evenings for parents, where the nature of 'real work' can be shown and where they too can share in a practical workshop session. There is no better way of showing the value of the work their children can produce through play and making than placing parents in a classroom situation. In a workshop they can experience the starting points and challenges that their children will already have experienced. Here they can see that making provides an effective way of absorbing, understanding, remembering and using information which acts as a stimulus to succeed and that 'working with hands' means the considered combination of all these skills. During one evening workshop, a parent who is an engineer commented that some apprentices had difficulty in understanding assembly instructions and thought that this early involvement was very helpful.

It is important for children to have contact with craftspeople as well as seeing real constructions in the environment. It is possible that a locally based furniture maker, sculpture, engineer or instrument maker would welcome a visit by pupils to their workshop or would come and visit the school. By examining real constructions, the relationship between material, form and function is presented and may be the spark to fire the imagination of a young child for the future.

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Chapter 2

Exploiting the Urban Environment

***Celia Clark** explains how teachers and parents may make use of their pupils' immediate environment to develop their spatial skills more effectively. She describes a number of projects which have been carried out with pupils in primary and secondary schools, and indicates how these may be integrated with construction projects such as those described in the previous chapter.*

1. Why Study the Urban Environment?

The urban environment is where most of us live: it is our most accessible context for learning. For over 90 per cent of us in the UK, and in many other countries, our homes, schools, leisure areas and workplaces are in urban areas – whether we live in a village, a town or a city.

Buildings and towns are amongst the greatest achievements of man's spatial ability. Architecture expresses the culture, economy and aspirations of a community. A town or city is more than just the sum of its inhabitants – buildings in relationships can give aesthetic pleasure which is essentially three-dimensional.

To experience buildings and places, two-dimensional forms such as maps, plans and elevations are only supplements to the first-hand experience of walking round them and through them, to living in them: 'The architect works with form and mass just as the sculptor does and like the painter he works with colours' (Rasmussen, 1964). Buildings grouped together and spaces between them give us an aesthetic pleasure which they do not give us separately.

Yet although buildings offer us our most common three-dimensional experience, adults are often oblivious to the familiar spaces of our lives, both inside and out. We never really see them or explore them in the fresh way that young children do. They ask: 'What's round the corner? Where does that gate lead to? What's on the other side of that door?'

The built environment is a huge, free, constantly changing resource, which provides a wealth of stimulating experiences relevant to many subjects. We can with practice rediscover our primary kinaesthetic experience of places. As teachers we can also gain confidence through working with other adults with skills in the built environment who can augment and complement our knowledge. Importantly, through urban studies we can add another, creative dimension to our lives: that of learning to change or enhance our living spaces. Through environmental education pupils can learn about their surroundings, and so begin to understand, and influence, the changes and decisions which affect their lives.

2. Built Environment Education and Spatial Ability

Built environment education holds exceptional potential for developing both pupils' practical spatial skills and their spatial thinking skills. It also provides many opportunities for increasing their knowledge and enjoyment of space, that is, of shape, form and structure.

All environmental education begins logically with experiencing an environment. This is usually a real-life environment, but it can also be entirely imaginary: created either by a storyteller or by the children themselves. By exploring real or imaginary places, children can substantially increase their spatial knowledge. With guidance, they can learn to see the underlying geometrical form of these features and structures. They can learn to recognise the building blocks that form architectural features and to see how these are combined to produce stable and aesthetically pleasing structures.

The act of recording their experiences in some way will help children to remember permanently what they have encountered. If the records are spatial in nature, rather than language-based, then important practical skills will be acquired, such as observation, sketching, measuring, collage and photography. Additionally, the process of sketching will help to develop their ability to estimate lengths, heights, angles and relative proportions.

Developing responses to experiences in the form of 3-D models provides a particularly rich source of spatial learning activities, as well as improving manual dexterity. Modelling will develop not only visual analysis, spatial judgement and practical skills, but also the intellectual skill needed to comprehend the relationship between different views of the same object: something which is fundamental to competent spatial thinking.

At its most simple level, built environment education consists of exploring, experiencing, asking questions of and recording the existing environment – often as part of a cross-curricular topic or as one aspect of a particular subject area, for example, history, art or science. At a more complex level, built environment education involves designing or planning some new feature of the environment. This necessarily exercises several types of thinking: linguistic, aesthetic, mathematical and social, just as much as spatial. The spatial skills developed by design are mainly intellectual, involving the use of spatial imagery and mapping to anticipate the likely consequences of some alteration to or construction in the environment. The design process may often be facilitated by creating models.

The 'making' component of built environment education, like modelling, will develop practical skills; but in this case the skills may be 'real-life' ones such as carpentry, brick making and laying, or metalwork, as well as observation and questioning. The act of constructing environmental objects will give valuable practice in judging lengths and angles; while developing, experiencing and evaluating the design will develop social skills and oracy.

3. Exploring the Built Environment

If the first stage in built environment education is becoming fully aware of the existing environment, then teachers will want to introduce experiences to heighten their pupils' awareness. Sensory experience via sight, sound, touch, taste, smell and movement is the foundation upon which we build our ideas about the world, so activities need to focus upon the pupils' sensations.

For people with normal sight, the visual sense will dominate all the others, and special techniques may have to be used to nurture the non-visual senses. 'Sensory walks', both inside and outside the school or home, are a good way of discovering a familiar place anew. If the dominant sense of sight is excluded with a blindfold, then all the sounds, smells and textures can be plotted along a route through familiar buildings, including the school. The route can be defined by a rope or string, and the children can work in pairs, reporting their findings. The scope for improving children's awareness of the sensory environment of visually impaired people by this means is obvious, particularly if such pupils or visitors take part in the activity.

While non-visual sensory walks provide an effective way of broadening children's sensory awareness, most exploratory work will, of course, need to include and develop visual awareness. There are several books that consider the experience of exploring the urban environment. *Art and the Building Environment* (Adams and Ward, 1982) has a whole series of exercises for inside and outside the school, such as using a series of instruction cards which guide pupils in exploration of their local area and 'steeplechasing' – sketching a dominant feature of the townscape from a sequence of different viewpoints as you approach it. It explains how looking for patterns or sequences, for example, of windows, in surfaces, textures, skylines can lead to outcomes in both art and dance. Gordon Cullen's *Concise Townscape* (1971) defines the processes of serial vision which towns offer: walking through a building or a place to provide a sequence of revelations. Enclosure and exploded space, the shifting interplay of towers, spires and masts, focal points, occupied territory, enclaves, indoor landscapes and outdoor rooms, visual blocks which close the view, magnet doorways or arches which invite you forward, changes of level, silhouettes, undulation, anticipation, mystery and infinity are explored.

Notation on these sensory walks may take the form of freehand sketching, rubbing or casting, poetry, dance or music. Wax crayons, pencil, chalk or charcoal can be used to make rubbings of interesting textures and features such as coalhole covers and memorial plaques as well as natural surfaces such as tree bark. A card frame will prevent unintentional graffiti! Using a tape recorder, a particular place – a shopping precinct or the school dining hall, for example – can be evaluated against a verbal scale over ranges such as dull to stimulating, resonant to muffled, dark to light, safe to dangerous, or welcoming to threatening.

Freehand sketching, (*never* with a ruler, which is only another thing to carry about or manipulate) is a vital tool to first-hand observation and to storing shapes in the mind.

The basic shapes of architecture – planes, curves, arches, squares, rectangles, circles, cones, cylinders, pyramids, domes, towers, spirals, slabs and blocks – can be stored in the spatial memory by planning a range of visits to the local area. Learning the appropriate specialised vocabulary will help link physical and verbal responses. Memories of the shapes and layouts of different places form a repertoire to which we constantly add.

For very young children, a collection of these basic shapes and their names could be used as a stimulus to looking for shapes and recording them. A team-based or individual exercise might improve motivation and give pupils with high spatial ability a chance to shine.

Round Buildings, Square Buildings and Buildings that Wiggle Like a Fish by Phillip Isaacson (1988), aimed at the middle school age group, explores the pleasures and knowledge that buildings can give us, in terms of light and colour:

> *'Windows are pathways to the spirit of a building. Some open a house to the world, others shut it away'; looking up: 'do you look at the roofs of buildings? You should, because that's where a building joins the sky. A roof may slip quietly into the sky as skyscrapers do, slice into it as Chartres* [Cathedral] *does, or even seem to push the sky aside like the dome of the basilica of St. Peter's in Rome.'*

As explained earlier, exploration of the urban environment can go beyond pure awareness-raising to focus upon particular curriculum areas. When looking at traditional building materials from the scientific, geographical, historical and artistic point of view, we need to recognise the link between them and the local geology, as in the use and colour of brick, stone or mud walls (cob), or timber frame, and the availability of other materials: timber, clay or stone tiles, thatch, slate. *Your House,* *the Outside View* by John Prizeman (1975), has a marvellous repertoire of dwellings in different materials, including the most up to date; and Alec Clifton Taylor's *The Pattern of English Building* (1972) is the chief source book for the study of historic building materials related to local geology. Modern building materials may come from much further afield – as may the design ideas. Building professionals may help identify sources.

The cultural contexts of buildings can be explored, with considerations of climate, materials, family and work patterns, and technological development. All play their part in how our towns and buildings come to look and function the way they do. Pupils may follow up this exploration by working with natural materials to construct buildings, or models of buildings (see Trevor Aldous, in Chapter 1 of this handbook). This will help them to develop a better understanding of how simple dwellings are built.

Questioning how and why decisions about the built environment are made will also further economic understandings: Why was this office block built here? What is the value of this land? Who has a say in what happens to it? Who owns this building? Who benefit from it? The roles of professional planners and of elected planning committees and of their perceptions of the environment can be explored through contacts with local government officers.

4. Modelling the Built Environment

Model making is a key stage in realising designs in three dimensions. It is as important to urban designers, town planners, architects, engineers and interior designers as it is to primary school children. Urban education is one way in which teachers can help dispel the damaging myth that modelling is 'only for children' or 'just playing with Lego'.

One of the most complex spatial skills is tying up (visualising) our experience of the inside of a building with the outside – some are deceptive or give misleading clues such as blocked windows. We must also be aware of constant change in the urban environment – a familiar building disappearing or changing its use, or a whole area being developed or redeveloped. Looking particularly at pupils' own homes, a diagrammatic representation of how the rooms are linked together can be a useful tool for analysing their function. To begin with, 'My Space' – or a space for a favourite person – may be explored, and a brief prepared, with a design to make a model to scale or full size. This approach may be extended to cover 'My Home', using the same processes but at a more complex level. The relationships of spaces, materials, construction and the elements of buildings, including doors, walls and roofs, must be considered, and pupils will have the opportunity to explore measurement, colour, texture, light and ergonomics. The challenge of integrating staircases between floors and cupboard space is one that might highlight those with spatial ability.

Although accurate drawing has its place in children's education, the conventions of drawings can inhibit expression of design ideas. Older pupils get diverted by the techniques of drawing and scale. All pupils can work in 3D, although model-making needs many skills of connecting shapes. Adhesive tape solves most problems and boxes become building spaces quite easily. Pitched (sloping) roofs are easy but domes and staircases are more tricky. Cut-out hands or fingers or a person (to scale) may be used to measure space in the models, or children themselves may measure real space with linked outstretched arms. Drawings do not necessarily match the models but they can develop or express spatial ideas. Pupils can embellish their models with furniture and decoration, again made approximately to scale.

Following on from the 'My Space' and 'My Home' projects, children may arrange their designs of homes in a city street or around a square, or group them along a village lane. This enables the modelling activity to develop naturally into a broader consideration of planning issues, working with town planners, architects, builders or surveyors and local community groups. They can discuss with the community the evolution of urban spaces, the character and style of buildings, their economic value and environmental impact, and their contribution to sustainability. 'Box city', using cardboard boxes, can be used to design and build new urban spaces in the school hall, or perhaps in a local shopping centre or library. These may serve to stimulate discussion among the pupils, and others who get involved.

This approach illustrates how urban education projects can begin by focusing on a specific environment and then progress to meaningful activities that can help to enhance diverse intellectual and practical skills: spatial, linguistic and social. The next section provides a range of further ideas for environmental starting points and follow-up projects.

5. Environments and Projects

The school building is the obvious, but often unconsidered, place to begin environmental explorations. You can examine it as a shelter from the weather, a collection of solids and voids, a pattern of spaces, or of windows and walls, or gables and parapets. It can be regarded as a demonstration of the educational ideas held when it was first built (with all the subsequent adaptations), a landmark in the local townscape, a work place, a natural habitat, a collection of materials, an asset (or debit) in the education service – or simply as a familiar place and shape. The school is the one building that the pupils, teachers and ancillary staff, governors and parents have in common.

Sharpening children's awareness so they experience the characteristics and sequences of the spaces in their school is an effective way of learning the skills to 'read' other buildings. One technique is to consider entrances: ways into schools are often extremely difficult to find. The obvious main door is blocked off, and you are forced to set off on a safari through playgrounds and corridors. Several schools have tackled this problem by redesigning the school's main public face.

> Gillespie Junior School in the Arsenal area of London, helped by the Islington Schools Environment Project, explored the history of their School Board building of the late nineteenth century. They noticed the architect's emphasis of the doorways and his love of the sunflower and other decorative motifs. Instead of the original white paint, they devised a colour scheme which emphasised the sculptural quality of the relief decorating the doorways. They had to convince the local conservationists and the planners of the merit of their designs, because Gillespie Junior School is a listed building.

Modern flat-roofed first and junior schools in Newcastle have devised traditional architectural doorways to mark their entrances. In Manchester, groups of pupils work directly with architects and landscape architects each year on a development project in or out of school. These have included a new music and drama block, buildings for African animals in a local zoo, new uses for a disused bus station, and designs for a new heritage centre in one of the city's historic spaces. Pupils learn to develop a design brief involving physical, cultural and conservation issues. The built environment professionals find the pupils' questioning stimulating, sometimes leading them to re-evaluate their own practices. They learn that although they might be experts, they do not have all the answers!

Improving other spaces in the school can prove just as challenging.

A class of 10 to 11-year-olds at Montagu Primary School were aware of the extreme discomfort of the environment in which they ate their lunch. With the help of the Newcastle Architecture Workshop, they spent a term investigating the problems: exploring the shape, textures and colours of the dining hall, measuring the existing space and layout and observing its use at lunch and over the school day, identifying the heavy traffic areas. They then replanned the layout to make a more informal café-like atmosphere, taking into account hygiene, sound and safety factors. They examined other designers' solutions in cafés and restaurants in Newcastle, which used screens and planting to subdivide the space, and prepared design ideas upon which the Fire Officer commented from the safety point of view. They discussed who owned and was responsible for the dining hall, considered questions of budget and suppliers, planned a presentation and were given feedback. One of the aims of the project was to make the children aware that they can affect the environment of their own lives, by becoming agents of change.

The school grounds and their immediate setting are another underused resource: whether the latter is a rural or mining village, an outer housing estate, a market town, an inner city or a central business district. All urban settlements have patterns or traces of their history which pupils can learn to read. Looking at the overall shape of the area or street pattern is especially rewarding with older pupils – they can compare it with a map series of the area of different dates from the local library, museum or records office to understand chronology and change over time.

Since children 'know' their home ground in quite a different way from adults, including unofficial routes, places to play, and where key people in their personal landscapes live, mental mapping is a useful exercise in exploring their perceptions of their home ground. They can devise their own maps, emphasising what is important to them. Alternatively, given a base map of the surrounding streets, pupils can be asked to mark in as many buildings as they can. Comparison of the results can be followed by a discussion on why some buildings and spaces are more memorable than others.

Some spatial projects are mainly focused on one subject rather than being cross-curricular. In history, you can build up pupils' sense of chronology by asking them to identify buildings of various dates along a time line. For this they may need to build up a repertoire of historical shapes – whether classical columns, the Golden Section related to Georgian window size, the jazzy pattern of Art Deco in cinemas, the huge many-windowed textile mills, curtain walls of office blocks, or the current mania for decorating buildings to make them look old. The owners of buildings to be visited should always be consulted. Often they will be only too pleased to show small groups of children round their properties and to answer their questions. They may be able to lend the school old pictures, documents or plans of recent buildings. People who may be invaluable are builders, architects, surveyors, planners, conservation officers in district and county council offices, members of local civic/amenity societies (who are particularly interested in issues of urban change, town planning and building conservation), members of local history societies, museum and archive staff, and older people with long memories of the place. Future-oriented projects are just as valuable. Children in Grampian, Scotland were asked to put forward ideas to make youngsters' experience of coming to hospital less daunting and upsetting. Children from seven schools presented their ideas in the form of drama, videos, poems, models, drawings and music to an audience of council, educational and health executives.

The teacher needs to survey the area thoroughly before the visit, establishing any hazards such as heavy traffic, finding safe places for the pupils to work, access to toilets, and to let people who are likely to be involved know of the visit – as well as obtaining parents' permission. Parents of younger children may like to come and help the children, adding their own local knowledge to the exercise – but make sure you brief them thoroughly on what you are expecting the children to do, and debrief them afterwards.

Once the skills, concepts and knowledge you want your pupils to gain are established, it may help their motivation to have a tangible end-product planned. A box city, a photographic or tape/slide programme, a video or exhibition, or a presentation of proposals for change could animate the whole process. This outcome could be presented to other pupils in the school or in feeder schools, parents or the local community; the audience might offer feedback to help pupils evaluate their work. Press coverage can be arranged – perhaps on local radio as well as newspapers. Original research might also be publishable by a local society.

Planning educational work round a local issue will sharpen the focus: a new biscuit factory or small open space, a building about to be demolished, local woodland being destroyed for housing, new uses for a piece of wasteland, flood relief measures, a proposed hot food take-away or a bypass through the town, or pollution of a stream or the seashore.

A class of nine-year-olds in the Midlands were concerned that a fine avenue of trees outside their school was to be cut down for road-widening. By careful measurement of the road widths and the position of the trees, they were able to establish that the widening could be achieved without their destruction. They learnt about the decision-making processes of local government, lobbied their councillors and MP, and convinced them of their case.

Fieldwork of this sort may be appropriate for pupils working at any level.

Pupils in another Midland school, a sixth-form college, made a study of professional football grounds in urban sites and measured their impact on the surrounding streets in terms of zones and levels of nuisance. These were mapped, and ideas for parking, re-routing and crowd control were submitted to the police. Their paper reached ministerial level.

These case studies demonstrate that many locally based projects are essentially long-term. By using the local environment, the richest and most easily available resource, to stimulate active learning, pupils can develop skills of observation and questioning, handling data, synthesis, cooperation in group working (as many real designers do), problem-solving, decision-making, communication and presentation. Multiple visits are easy to manage, and the pupils gain from close study of a real place or problem. Having had that vital personal experience on their own home ground, young people have the base on which to develop their understanding and to evolve their own attitudes and values about the wider world and their place in its past, present and future.

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Addresses

The following addresses may be useful:

Building Experiences Trust
2 Baldwin Terrace
London, N1

Tel: 0171 704 0083

Chartered Institute of Building
Englemere
Kings Ride
Ascot
Berkshire
SL5 7TB

Tel: 01344 23355

Civic Trust
(+ Local/Civic Amenity Societies' addresses)
17 Carlton House Terrace
London
SW1Y 5AW

Tel: 0171 930 0914

Council for Environmental Education
University of Reading
London Road
Reading
RG1 5AQ

Tel: 0118 9756061

English Heritage Education Service
PO Box 229
Northampton
NN6 9RY

Web site: http://www.english-heritage.org.uk

Learning Through Landscapes
3rd Floor
South Side Offices
The Law Courts
Winchester
SO23 9DL

Tel: 01962 846258

(This organisation campaigns internationally to improve school grounds.)

Places for People (National Association for Urban Studies)
c/o ETP
9 South Road
Brighton
BN1 6SB.

Tel: 01273 542660

Royal Institute of British Architects & Local Chapters of Architects
66 Portland Place
London
W1N 4AD

Tel: 0171 255 1541

Royal Town Planning Institute & Regional Branches
Director of Public Affairs
26 Portland Place
London W1N 4BE

Tel: 0171 636 9107

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17 Carlton House Terrace
London
SW1Y 5AS

Tel: 0171 930 8903

Chapter 3

Reading and Using Maps

Geography is a spatial subject. Maps are essential for geographical work inside and outside the classroom. ***David Boardman*** *shows how the use of maps and the development of fieldwork techniques are integral to pupils' understanding of such underlying geographical concepts as location, distance, direction, and relief.*

1. Location

Children have a natural interest in their environment. This provides a basis on which a more formal understanding of location can be developed.

A-Z street maps and Geographia road maps both employ a system of squares identified by letter and number coordinates. Pupils should learn to use the index of street and road names for their local area and locate examples in the appropriate squares. They can work out the best routes between different places on the map, such as from home to school, or from home to the town centre.

In order to locate their own position and features outside the classroom, pupils need a more detailed, large-scale Ordnance Survey map. Urban areas are mapped at the 1:1250 scale (1 centimetre to 12.5 metres) and rural areas at the 1:2500 scale (1 centimetre to 25 metres). The storage of digital map data on computers enables the Ordnance Survey to print a large-scale map of the locality centred on the school. This shows individual houses, gardens, shops and other buildings. All roads are named, so that pupils can locate specific buildings and their grounds. Maps at the 1:10,000 scale (1 centimetre to 100 metres) show buildings, roads and topography over a larger area.

The use of number coordinates is a mathematical skill which is applied in geography. In mathematics, pupils learn to specify location by means of coordinates, for example, to plot points on a line graph. After learning this skill, they should apply it by using four-figure grid references to locate squares on an Ordnance Survey map at a scale of 1:25,000 (4 centimetres to 1 kilometre) or 1:50,000 (2 centimetres to 1 kilometre). The numbers of the grid lines on a map start in the lower left-hand (south-west) corner and increase to the right (east) and upwards (north) in the same way as the numbers along the x and y axes of a graph. Just as the number on the x axis is given before that on the y axis, so on a map the easting (east of the point of origin) is given before the northing (north of the point of origin).

When learning to locate a point by means of a six-figure grid reference, pupils may find it helpful to superimpose on the kilometre square a 10 x 10 grid of small squares printed on tracing paper. Pupils should learn the method of giving a six-figure reference which is clearly explained on every Ordnance Survey map. For the purposes of practice they should locate on maps point features (e.g. a church or public house), line features (e.g. a road or railway), and area features (e.g. a park or woodland).

2. Distance

A wall display of maps of the local area on different scales is useful when introducing pupils to the concept of scale on maps. If the same one-kilometre grid square is highlighted on the 1:10,000, 1:25,000 and 1:50,000 maps, pupils will see how the amount of detail in the grid square is reduced as the map scale becomes smaller, and appreciate that every map is selective in the features it shows. The map at a scale of 1:250,000 (1 centimetre to 2.5 kilometres) can also be included in the wall display because it locates the local area in its wider region, and provides a link between medium-scale topographical maps and small-scale atlas maps.

Measuring distances on maps of different scales is another example of how skills learned in mathematics are directly applied in geography. In mathematics, pupils learn to use unitary ratios, such as a ratio of 1:50 to draw a plan of a classroom, and to use decimal notation in the context of measurement, as in reading scales marked in hundredths and numbered in tenths. In geography, pupils should learn to measure the straight line distance between two points on a map, using the scale line provided. They should also work out the distance along a curved route such as a road by breaking it down into short sections, marking these along the edge of a sheet of paper, and then measuring the total length of the route.

On medium-scale maps, pupils should be able to work out distances in both miles and kilometres, especially as road signs in Britain give distances in miles. Pupils should know, for example, that on a 1:50,000 map, two centimetres represent one kilometre, or 1.25 inches represent one mile, and calculate distances accordingly. They should also develop some understanding of what distances measured on a map are like on the ground. Some pupils may find scale measurements on maps difficult, and a useful framework for devising differentiated tasks for pupils of a range of abilities in the same class is provided by Slater (1996).

3. Direction

Pupils should understand the eight points of the compass, and should be able to give the direction of one place from another on a map. They should also learn to use a compass in the playground: remembering that the needle points north, they can walk round the outside of the school building, noting the changes in direction. As a further check they can align map and compass in the playground and later elsewhere in the local area.

A further skill is that of following a route on an Ordnance Survey map and describing the features which would be seen. This is a useful exercise because route following is one of the main purposes for which maps are used in adult life. Pupils should also learn to use maps on appropriate scales to plan routes, and should note that different kinds of maps are used for different purposes: 1:25,000 Pathfinder maps for planning walks in detail; 1:50,000 Landranger maps for walking, cycling and local motoring; and 1:250,000 Travelmaster maps and a range of road atlas maps for longer journeys.

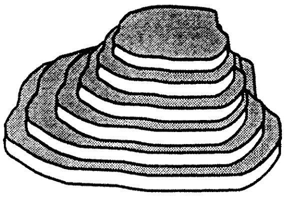
Computer programs are available to enable pupils to practise their map reading skills, particularly grid references, distances and direction. Some programs are in the form of games which require players to navigate their way from one place to another. Developments in digital mapping permit large quantities of map data to be stored in computer software. Thus the Ordnance Survey has produced CD-ROMs which enable pupils to scroll round a city studying maps and aerial photographs. They can zoom in from 1:50,000 to 1:10,000 and 1:2,500 scales, and attempt structured activities which provide practice in giving grid references, following routes and measuring distances.

4. Relief

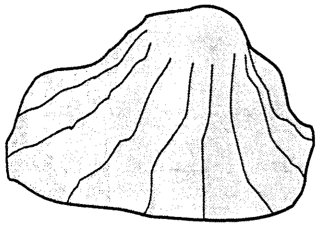
Relief is usually shown on topographical maps by means of contours. These are numbered lines which give the height of the land above sea level. The land on one side of a contour line is lower than the height indicated, and on the other side it is higher. The concept of contours is one which many pupils find difficult and they are likely to understand it better if visual aids and practical activities are used. A simple technique for introducing contours is to cut a potato in half and then into further slices. If these are reassembled, the edges of the slices illustrate the basic idea of roughly circular contours round a hill.

To assist pupils to visualise the relief of a small area from a map, the contour pattern can be built up into a relief model. An Ordnance Survey 1:10,000 map is required as this is the largest scale on which contours are shown. The map of the local area is ideal if it contains sufficient variations in relief. A small area of the map is selected and enlarged, either on a photocopier with an enlarging facility or by projecting an overhead transparency on to a sheet of paper pinned to the wall and drawing the contours on it. A piece of strong cardboard the same size as the enlarged map forms the base of the model.

The lowest contour is transferred from the map on to another piece of cardboard or a large polystyrene ceiling tile by pressing a sharp pencil or ball point pen through the paper along the contour at closely spaced intervals. This produces a row of dots on the tile or cardboard, so that tracing paper is unnecessary. The shape of the contour is cut out and glued in position on the base of the model. Pencil marks are made on it to indicate the position of the next contour. The process is repeated for successive contours, each shape being glued on to the one below it, thus creating a layer model.



Model under construction



Model after completion

Although the edges of the tiles or cardboard layers represent the contours, the stepped or terraced appearance of the model does not resemble the real landscape. The spaces between the layers, therefore, should be filled in with plaster or filler and smoothed out. When dry the model can be painted green and selected features can be added in other colours, such as a stream in blue or a road in black. If the model is intended for permanent display or demonstration purposes, it is useful to place alongside it a copy of the contour map and an incomplete terraced layer model to show the method of construction, as recommended by Rhodes (1994). It is important to remember that the thickness of the layers of cardboard or polystyrene in the model exaggerates the steepness of the relief in the landscape. The procedure for constructing models of this kind is described in more detail elsewhere (Boardman, 1996).

When looking at a 1:25,000 or 1:50,000 map for the first time, pupils should try to form a general impression of the relief over the area. They can do this by looking for the highest points, often indicated by numbered spot heights near to closely spaced contours, and the lowest points, usually found in valleys occupied by rivers, streams or lakes. They should note that the tops of the height numbers are printed on the higher side of the contour line. The 1:250,000 map is valuable for gaining a realistic impression of topography because relief is shown by means of layer tinting and hill shading as well as contours.

Developments in computer software enable contour patterns to be converted into three-dimensional representations of relief on the screen. Digital terrain modelling has been developed for use with digitised Ordnance Survey maps. Contours on a 1:50,000 or 1:25,000 map can be raised on the screen to produce a three-dimensional model of relief over the whole of the map, thus showing the relationship between relief, river, settlements and communications.

5. Atlases and Globes

Most of the skills required for reading large- and medium-scale maps are also applicable to the small-scale maps in atlases. The coordinates are different, however, and pupils should have practice in using the index and finding places on the appropriate maps, given their latitude and longitude. Relief is shown on most atlas maps by means of layer tinting or hill shading, making it easier to identify highland areas. Thematic maps, such as those showing population density or annual rainfall, also employ layer tinting or different densities of shading. On political maps, colours are simply used to differentiate between countries and highlight their boundaries.

Atlas maps should be compared with those on globes. Latitude and longitude, the north and south poles, and the hemispheres are effectively demonstrated with the aid of a globe. A three-dimensional hemisphere cannot be pressed flat on to a piece of paper, so the segments of the hemisphere have to be separated by gaps on atlas maps. Approximate distances can be measured on a globe with a piece of string. On most world maps, however, distances cannot be measured because the scale is usually constant only at the equator.

Pupils who have learnt the essential skills for using atlases may investigate atlas maps which are available on CD-ROMS. Thus the Ordnance Survey Interactive Atlas of Great Britain displays on the computer screen maps on a range of scales, together with aerial photographs and three-dimensional models. Electronic atlases usually have a zoom facility which enables pupils to select part of a map and enlarge the scale. The Distant Places Interactive Atlas produced by the Advisory Unit, Computers in Education, is accompanied by worksheets containing structured exercises on maps displayed on the screen.

6. Aerial Photographs

An aerial photograph is in many respects easier to comprehend than a map because it shows the actual view instead of a symbolic representation of it. The study of aerial photographs can thus help pupils to understand spatial relationships without having to refer to symbols. They should use aerial photographs to identify landscape features in contrasting physical environments and to interpret land use patterns in different human environments. Aerial photographs are excellent for showing relationships between physical features and human activities.

On an *oblique* aerial photograph, the effect of perspective means that the scale varies from foreground to background, with the result that it is often difficult to compare the photograph with a map of the same area. On a *vertical* aerial photograph, however, the scale is constant, so it is instructive for pupils to look for differences between map and photograph. They can list features that the photograph shows but the map does not (e.g. buildings and traffic), and features that the map shows but the photograph does not (e.g. names and boundaries).

A satellite image is really a special kind of vertical aerial photograph taken from a great height. As such, an image resembles an atlas map in scale and complements it by showing regional patterns of urban and rural land use. Images may be in true colour, giving a green leaf effect to vegetation, or in false colour, giving vegetation a red effect. Much greater environmental information is provided by infra-red radiation from the earth's surface, so that false colour composite images are more frequently used to display satellite data. Using the colour key which is provided with each image, pupils can attempt to identify spatial patterns in land use. If a satellite image is compared with an atlas map of the region on a similar scale, the selective nature of an atlas map is revealed. Smaller settlements and minor roads, for example, are omitted from the map in order to avoid obscuring detail.

7. Fieldwork

There can be no substitute for the comparison of the map with the ground it represents. Geographical fieldwork provides ideal opportunities for pupils to practise and apply their map skills. In all work outside the classroom, the safety of pupils is of paramount importance, and it is essential to comply with school and local authority regulations on this matter. General guidance on fieldwork planning, organisation and safety is provided by Bland *et al.* (1996). Maps are required for the three main approaches to fieldwork which they identify: look-and-see, investigative, and enquiry-based.

The 1:1250 or 1:2500 map forms a good base on which pupils can plot the use of buildings or their age, or the materials of which they are built. If pupils record such features by means of a key consisting of letters and numbers, they can transform these into colours on a further copy of the map in the classroom. Colour maps of this kind enable spatial patterns to be readily identified.

Large-scale maps are also useful in fieldwork which encourages pupils to consider the changes that would occur in a landscape or townscape if a new road or bypass were to be built, particularly if it would necessitate the demolition of existing buildings or loss of agricultural land. A map is essential for making decisions on the best sites for such features as a new factory, housing estate or superstore.

Geographical fieldwork in rural areas enables pupils to extend their observations to larger plots of land at varying heights, such as fields, woodland and moorland. Ordnance Survey 1:10,000 and 1:25,000 maps show field boundaries and provide a good base on which to record land use. Measurements of the flow of water in a stream may be taken at a number of points along its course, all of which need to be recorded on a map. The locations of soil samples taken on different parent rock types also need to be plotted on a map. Fieldwork may involve hypothesis-testing, problem-solving and scientific method, but invariably reference to maps is an integral part of work in the field and in follow-up work in the classroom.

8. Orienteering

Orienteering is a recreational activity and sport which offers excellent practice in reading and using maps, and can be attempted in some form by pupils of all ages. A simple course can be set up in the school grounds; an example is provided by Lawes (1995). Control points are indicated by means of markers, such as large cards bearing numbers and letters. Their positions are marked on the map by circles and numbers. Pupils set off at timed intervals and use the map to find each control point in turn. They record its code letters in the appropriate space alongside their map to prove that they have visited the control. A wide range of orienteering exercises for pupils of different ages will be found in a book by McNeill *et al.* (1992).

In some parts of the country, permanent orienteering courses have been set up in parks and woods. Orienteering maps are specially drawn on scales ranging from 1:5,000 to 1:15,000, and show the nature of the terrain by means of contours, colours and symbols. The start of the course is marked on the map by a red triangle, and the positions of control points are shown by numbered red circles. Control points along the course consist of posts bearing red and white circles, together with their control numbers and code letters. Orienteers proceed from one control to the next in the set order and copy the code letters into boxes printed alongside their maps as proof that they have visited each control.

As a competitive sport for children and parents, orienteering involves finding control points with the aid of map and compass. Control points are large orange and white 'kites' hung in prominent positions at the features circled on the map. Each control has a description and code number, and attached to it is a punch with a unique pin pattern which competitors use on their cards as proof of visiting each control. Frequent decisions have to be made about the best route to take between one control and the next. A knowledge of contour patterns is important because the shortest route on the map is not necessarily the quickest on the ground. For example, it may be quicker and easier to follow the contours round a hill than to take the apparently shorter and more direct route over the top of it. Speed is essential in finding control points, the winning competitor being the one who completes the course in the fastest time.

9. Conclusion

Maps form an integral part of geographical work and make a valuable contribution to pupils' spatial understanding. The role of the teacher is crucial in helping pupils to *learn* the essential skills required in reading and using maps. When pupils have acquired the necessary competence with maps, they should *practise* their skills at the computer, using the software now available, and in fieldwork, using maps on different scales. In a short chapter it is possible only to outline some of the ways in which pupils can learn to read and use maps inside and outside the classroom. Further details of the methods and activities will be found in the references below.

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Addresses

The following addresses may be useful:

The Advisory Unit
Computers in Education
126 Great North Road
Hatfield
Hertfordshire
AL9 5JZ

Tel: 01707 266714

British Orienteering Federation
Riversdale
Dale Road North
Darley Dale
Matlock
Derbyshire
DE4 2JB

Tel: 01629 734042

The Geographical Association
160 Solly Street
Sheffield
S1 4BF

Tel: 01142 960088

Ordnance Survey
Romsey Road
Southampton
SO16 4GU

Tel: 01703 792795

Chapter 4

Mental Shape and Space

> *It is obvious that thinking about space is important in geometry. It is also important in other branches of mathematics: early number work involves the mental organisation of the objects one is counting; calculations often rely on the images one has of place value or the spatial arrangements of numerals on paper; ideas about functions can be assisted by pictures of their graphs.* ***David Fielker*** *suggests ways in which mental imagery can be developed in the mathematics classroom.*

1. Introduction

Spatial thinking has a significant role in many school subjects, in everyday life, and in many occupations. Consequently it is important that full advantage is taken of the opportunities afforded by mathematical work in shape and space to develop children's use of spatial imagery.

Within mathematics, work in shape and space requires mental activity at different levels. Even if pupils are handling objects or working with diagrams, there is still some mental work involved in imagining how things are going to look if alterations are made, in making decisions about what changes are necessary, or in determining where additions are to go. For example, building a symmetrical pattern with blocks demands a mental picture of how each stage is going to appear when each new block is added, and drawing a line of symmetry on a diagram requires its prior mental insertion. Work in three dimensions demands more complex mental skills in perceiving relationships even when shapes are being handled, and the relationships between three-dimensional shapes and their two-dimensional representations – drawings, nets or plans and elevations – can be complex. Thus a great deal of mental activity is involved in normal practical classroom activities.

But it is also possible to engage pupils in work with greater degrees of imagery by removing the support of physical objects until they are operating entirely in their heads. Cutting an actual rectangle in half is different from *imagining* cutting a rectangle in half.

Somewhere in between the largely physical and the purely mental there is opportunity to combine both: on occasions when a physical operation is to be carried out, a teacher can say: 'Wait! Think about it first, and then do it.' So, *before* pupils unfold a piece of paper from which a hole has been cut, they can be asked what they think they will see.

It is a common phenomenon that many adults, brought up at school in a two-dimensional world of paper, blackboard and books, find three-dimensional thinking difficult, and that children used to the apparatus found in modern classrooms find it easier. There is a case for starting on mental work as early as possible. This will promote a flexibility of thinking before pupils become too set in their concrete or two-dimensional ways. It will also prepare pupils to use their spatial thinking skills throughout their school careers.

Regular attention to spatial imagery will not only help to develop these valuable skills, but it will also have several other related benefits. Pupils will gain a greater awareness of their capacity to use spatial imagery. Teachers will discover which pupils have particular strengths in this area, and, given the lack of relationship between spatial and verbal skills, this may well yield some surprises. Finally, explicit attention to imagery will send a clear message to pupils (and to their parents) that spatial thinking is a key intellectual skill, thereby providing a much-needed boost to the self-esteem of those pupils whose spatial ability exceeds both their verbal ability and their general academic attainment.

2. Planning

The remarks above will indicate the different ways in which mental activity can be carried out in the classroom. It will be a part of much normal work, and on such occasions it is only necessary for the teacher to be consciously aware of how much of this work is mental. There are times when the teacher can interrupt physical activity, with the whole class, or with a group, or with an individual, and ask for a prediction about what will happen. And on occasions there can be sessions devoted exclusively to work in the head, with or without some physical props. The equipment needed for the activities described below will be that normally found in classrooms.

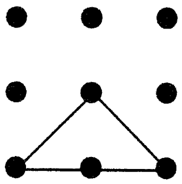
3. Language and Discussion

It is important to allow full and free discussion of the pupils' mental work. There are limitations to the pupils' participation when this is conducted with a whole class. However, a compromise can be reached if the whole class work on the activities, but they discuss them in pairs or in small groups. The disadvantage here is that the teacher has less opportunity to hear what is being discussed, so she or he must surrender some knowledge of what is going on in return for the advantage of pupils having more opportunity to take part in the discussion. Otherwise, it is better wherever possible for the teacher to work with groups, or to take advantage of the occasional short conversation with a single pupil.

In their discussions, pupils will develop their mental strategies and awareness. They will reinforce and refine their own ideas through their explanations, and they will reconsider and develop what they see and do as they compare with the strategies of others.

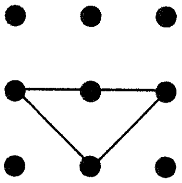
They will also develop their vocabulary as they explain their mathematical ideas. Here the teacher's participation is more necessary. While it is best to allow the pupils to pursue their struggles to explain things in their own words, it is also important that the teacher continually, at the right moment, provides the technical vocabulary which will enable the pupils to converse more efficiently. This needs careful timing. A lot of discussion can take place, for instance, about a shape being 'turned over' or 'turned round' or 'turned upside down' before the ideas of *rotation* and *reflection* are distinguished and named.

Language is important as a means of communication, but it is not always reliable. Teachers have to judge which is the best way for pupils to describe their images on any occasion so that they, the teachers, know as far as possible what those images are. For instance, it has been found that five-year-olds often think of a triangle in terms of its corners or 'points' rather than its sides. This focus can be revealed by verbal description or by physical indication. Sometimes it is revealed merely by a conflict, as when a pupil insisted that this triangle made with a rubber band on a geoboard had four corners!



In the case of reflections and rotations mentioned above, the teacher has to judge carefully if and when the attempts of the pupils to explain what they mean in words can better be replaced by a physical demonstration.

The relationship between words and images is complex. Generally an image has to come first, and then it can be described or demonstrated in some way. And, as indicated above, a technical word only makes sense as a label when the image is already there. But a word does not always conjure up the expected image. Children as old as 11 have been known to agree that a triangle has three sides, yet reject this as a triangle



because it was 'upside down'. And a class of 12-year-olds were once divided as to whether a sheet of paper had two sides or four sides, although that was easily resolved by the teacher ascertaining that everyone knew what was meant by 'side'. This may mean that an image prior to a word is only a first approximation, and the meaning of that word then needs to undergo continual refinement as further images are considered.

4. Some Activities

Activity 1: Same or Different?

Work with a group.

Ask each pupil to make a shape on a nine-pin geoboard with a rubber band.

Ask if any are the same. Ask how they are the same. Ask how they are different. Encourage pupils to distinguish between those which are exactly the same and those *which are the same only in some respects. Remove duplicates and possibly replace them with other shapes that are different. Discuss these in the same way. Eventually you will end up with a set of shapes that the pupils agree are all different.*

The idea of sameness is not always easy, but the vagueness of the question is deliberately intended to provide an ambiguity that necessitates discussion. Two triangles may be the same if you 'turn one of them round', and the teacher can recognise that the pupils have ideas of *congruence* and of *rotation*. The pupils may insist that, in spite of the congruence, the orientation makes the shapes different. True, the geoboard can be rotated, although some commercially produced ones have a trade name printed on them that, for some pupils, determines the orientation! It is best to leave decisions to the children. The important idea at this stage is not so much to remove duplicate shapes from the set, as to promote a consideration of the properties of the shapes and the relationships between them.

Pupils often want to come and manipulate the geoboards themselves. If you can insist that this should be left as a last resort, then this will encourage them to perform the transformations mentally. It will also force them into more precise instructions, especially if you pretend to misunderstand vague ones like 'turn it round'.

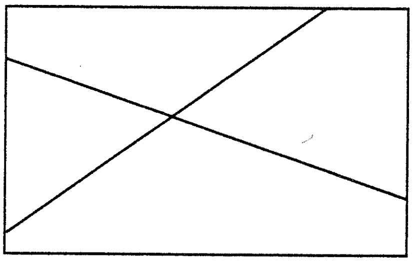
When you have a set of shapes which everyone agrees are different, select one and hold it up. Ask if there are any others which are the same in some way. For each suggestion, ask how it is the same, and how it is different.

Repeat this part of the activity for other shapes.

Again, the aim is a discussion of samenesses and differences, and the consequent ideas about properties and relationships.

The 'Same or Different?' activity can be carried out for any set of 2-D or 3-D shapes. Some are commercially available, or pupils can make their own in other ways. For example:

Ask pupils to draw two straight lines right across a rectangular sheet of paper, cut out the resulting shapes, and classify those as 'same' or 'different'.



Here there is opportunity to put into practice one of the suggestions above. Ask the pupils first to *imagine* where the two lines could go. Do they have to intersect? What shapes are possible? What is possible just with one line? What about three, or more, lines?

Activity 2: Four Squares

This activity is best done with a group. Working with a whole class is possible, but maybe two-centimetre squares would be more easily seen. Or the shapes could be displayed on an overhead projector.

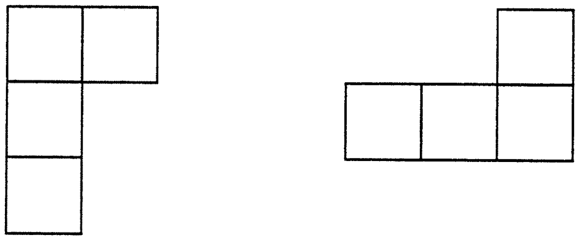
Give out centimetre squared paper and scissors. Ask each pupil to cut out a shape made from four squares, and write his or her name on it. Collect these as they are done and pin them up so that all can see them. (The names are partly to identify whose is which shape, but also to establish the intended orientation.)

Ask the pupils to check that all the shapes are made from four squares. Sometimes they make shapes from half-squares, or join squares at corners. The pupils themselves should decide what is permissible.

Ask if any shapes are the same.

In this context, congruence is usually the most obvious criterion for deciding whether two shapes are the same. As in the previous set of activities, pupils tend to suggest that one shape will be the same as another if it is 'turned round' or 'turned over'. By purposely misunderstanding, you can encourage more precise instructions. In turn, the demand for greater verbal precision can lead to more precise imagery as the ambiguities are revealed. Pupils should distinguish between rotating in the plane of the shape and 'flipping' to simulate a reflection. Rotation should be accompanied by an angle and a direction: 'Which way and how far do I rotate?' Flipping should be about a horizontal, vertical or oblique line. The two possibilities for oblique lines should be accurately distinguished. There is always the option of pupils demonstrating what they mean physically, by hand movements or by manipulating the shapes.

There are different ways of transforming a shape from one orientation to another. Pupils may suggest that the left-hand shape below can be transformed into the right-hand one by rotating clockwise through a right angle, then flipping horizontally. It can also be done by (i) rotating anticlockwise through a right angle then flipping vertically, (ii) flipping horizontally then rotating anticlockwise, (iii) flipping vertically then rotating clockwise, (iv) flipping about an oblique line at 45°, as well as several other combinations. The important things are a flexibility of mental imagery and the development of ideas about rotation, reflection and angle, with corresponding terminology.

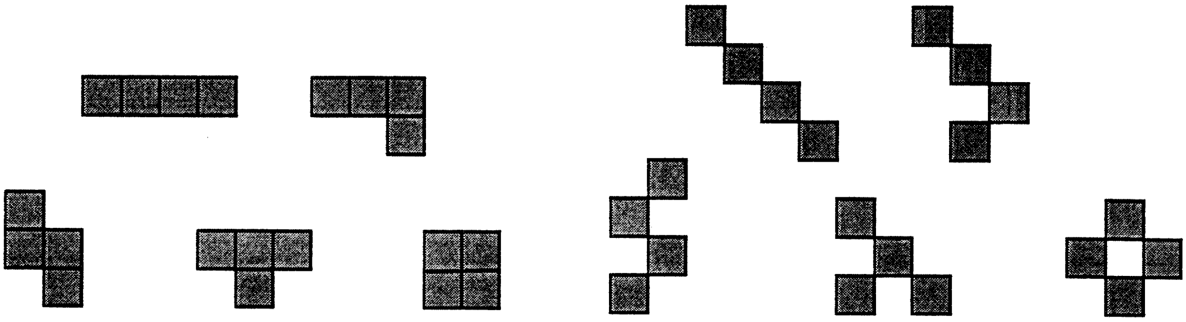


One of the things pupils may notice is that shapes with any form of symmetry have different possible orientations and can look 'the same' after a rotation or flip.

When duplicates have been removed, the remainder can be sorted. Some shapes will have their squares completely edge-joined, some may be completely corner-joined, and some may be mixtures.

Ask if there are any other shapes that can be made with four squares which are completely edge-joined. Check new suggestions against existing shapes. Continue until the pupils think they have all the possibilities. Ask for some justification of why they think so.

It is possible to consider corner-joined shapes in the same way, and there is a correspondence between the two sets.



The 'mixtures' may be more difficult to complete.

Four squares usually provide the right sort of challenge. Three would be too trivial. Pupils can go on to look at five squares, and return to three, or even two, for the sake of completeness. For edge-joined squares, this is part of a general investigation of polyominoes. But note that the actual numbers of possibilities are not as important as the ability to decide that all have been found.

It is also interesting to consider a similar activity based on equilateral triangles rather than squares, using isometric paper. The transformations are now in terms of multiples of 60° rather than right angles, and this is generally more difficult – which is a reason for trying it, not avoiding it!

Activity 3: Imagine a Square

This set of activities works well with a whole class, since the initial discussions are followed by individual or group work.

Begin with the following instructions and questions, to be conducted entirely mentally.

'Imagine a square.
Cut a little piece off each corner, in a symmetrical way, the same off each corner.
What do you now have? How many sides?
What can you say about the sides? What about the angles?

The sides are alternately long and short.
If you go on cutting, keeping the cuts parallel to the original cuts, can you make all the sides the same length? What do you have now?

Go on cutting. The original short sides become long, and the long ones become short.
Soon the cuts meet each other. Where do they meet? What do you have now?
How does this square relate to the original square?

Go on cutting, keeping the cuts parallel to the original cuts.
What happens? Where do you stop?'

Repeat the activity for an equilateral triangle, for a regular pentagon, for a regular hexagon, for a regular polygon with 100 sides.

It is doubtful if pupils can actually visualise a shape with 100 sides in the same way as they can the others, and possibly they are merely extrapolating the rule. But maybe they are visualising in a generalised sense, by imagining what happens to one of the corners, and then mentally transferring that to the others.

This introduction has two possible follow-ups.

(i) Imagine a tessellation of squares, and cut a piece off each corner of each square in the same way, saying what happens to the squares (we know this already) and what happens to the 'holes' that appear.

Repeat for tessellations of triangles and of hexagons.

Now the pupils can work practically at producing the tessellations on paper. They can also use the idea on other tessellations; for instance, if one starts with a tessellation of octagons and squares, what happens if corners are removed from all the octagons and squares?

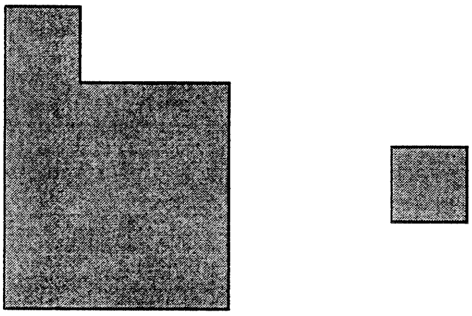
(ii) Imagine a cube. Cut a little piece off each corner. Carry on in the same way, stopping at critical stages to discuss the shapes of the faces, how they are joined, and how many there are.

This can be difficult, and it may help to have an actual cube in view: there is still some mental imagery left to do! If the cube is, say, a wooden one, then pupils may need to draw appropriate lines on it, but this still makes it necessary mentally to decide first where to draw the lines, and then to picture what happens inside the cube. As a last resort, one can physically cut corners off a cube of potato or modelling clay.

The critical stages are any where regular polygons are produced as faces. The pupils can now make a series of models. They can do this using the various commercial kits which enable plastic or cardboard polygons to be fixed together, or they can design and cut out nets. The latter is more suitable for older pupils, and it also involves some mental work in designing the nets. Another advantage of the home-made models is that they can be made in correct relation to each other.

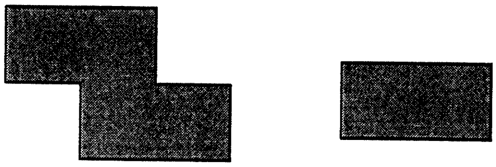
Activity 4: Add a Square

In how many different ways can the square be attached to the other shape so that the result is symmetrical?



This exercise can at least initially be presented, on a chalkboard or an overhead projector, as a mental one. It is fairly easy to imagine the square being taken round the other shape, stopping at each place to consider whether the result is symmetrical. Pupils generally can appreciate a vertical axis of symmetry more easily than a horizontal one, and either more easily than an oblique one. And they may not think of rotational symmetry unless prompted. If this exercise is presented on, say, a worksheet, then the pupils have the option of rotating the paper to make a prospective axis of symmetry vertical. They also have the option of physically moving a square round the other shape, but then there is still some mental work to do in recognising the symmetry when it is produced.

If an oblong has to be attached to another shape,

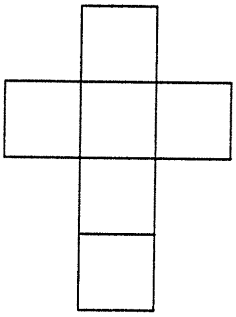


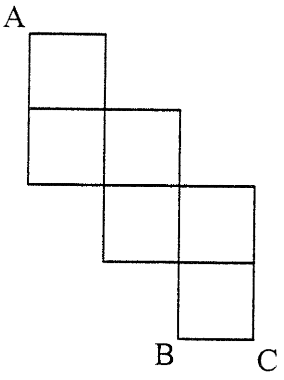
then this is more complicated because one has to consider two orientations of the oblong. Other examples can easily be made up, or the pupils can make up their own.

Activity 5: Nets of a Cube

How many different nets are there for a cube?

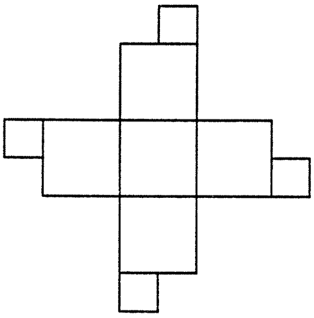
Most pupils will have met the 'cross', but there are several others. Pupils at upper primary or lower secondary level quickly produce a variety, drawing them on squared paper. They use mental imagery to design the net in the first place, and then again to check whether it will form a cube when folded up. One can focus on the mental imagery of folding up by presenting, say, the following on an overhead projector

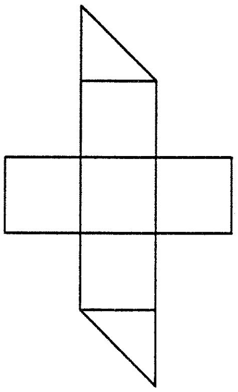


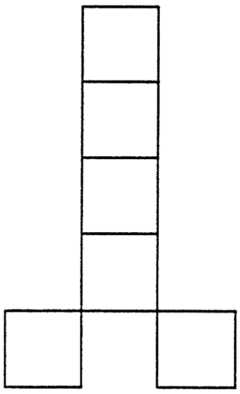


and asking questions like: which edge will meet BC? Which other corners will meet corner A? One can also discuss the strategies that pupils use. A common one seems to be to fix a square as a base and then consider the 'sides'. One can then ask questions about the above figure like: if this square is the base, which one will be at the top?

Pupils sometimes use a great deal of imagination (in the sense of originality as well as in the sense of imagery) by constructing 'nets' such as the following.







When one considers that these examples were only drawn on squared paper by some 11-year-old pupils and not cut out and folded up, one can appreciate the amount of visual imagery that was taking place.

The cube is probably the easiest shape to deal with in this way. One can also investigate different nets for cuboids, tetrahedra (triangular pyramids) and other common shapes.

5. Monitoring and Assessment

Teachers are often surprised at the variation between spatial skills and verbal skills. Pupils usually thought not so capable at mathematics can reveal high powers of imagery, and those normally thought of as the better mathematicians sometimes show a lack of ability to visualise. This is why it is so important that these different abilities are carefully assessed.

Generally such mental activity is neglected, and all pupils could benefit from more opportunity to practise it. Those finding it difficult may need particular help. It is also important, especially where the ability appears to exceed more commonly assessed abilities, that it is used, recognised and reported along with other information to other teachers, to parents and to the pupils themselves.

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BEENEY, R., JARVIS, M., TAHTA, D., WARWICK, J. and WHITE, D. (1982). *Geometric Images.* Derby: Association of Teachers of Mathematics.
(A collection of ideas for activities, with accounts of work with pupils, mainly at key stages 3 and 4.)

FIELKER, D. (1993). *Starting from Your Head: Mental Geometry.* London: BEAM.
(A rationale for mental work, and many activities at key stages 2 and 3.)

Chapter 5

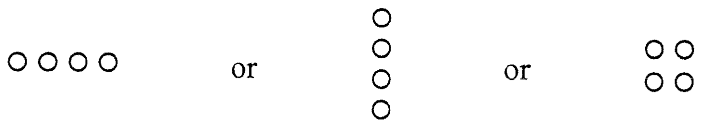
Arithmetic for Spatial Thinkers

> *Mathematics is not an obviously 'linguistic' subject. None the less, the linear, printed word which dominates the whole of the school curriculum affects mathematics as well (see the Introduction to this handbook). Arithmetic may be reduced to a series of algorithms, to be learnt and followed, with little understanding for many pupils.* ***Tandi Clausen-May*** *considers some alternative ways to teach arithmetic to pupils who think more easily in pictures than in words.*

Pupils who have stronger spatial than linguistic abilities are clearly likely to struggle with aspects of the language curriculum, but they may do better with such spatially based subjects as geometry. Other areas of the mathematics curriculum, however, are not so clear cut. Algebra and arithmetic, for example, may be presented in such a way as to support, or to obstruct, the spatial thinker. This chapter offers some suggestions to help spatially biased pupils to develop an understanding of aspects of number.

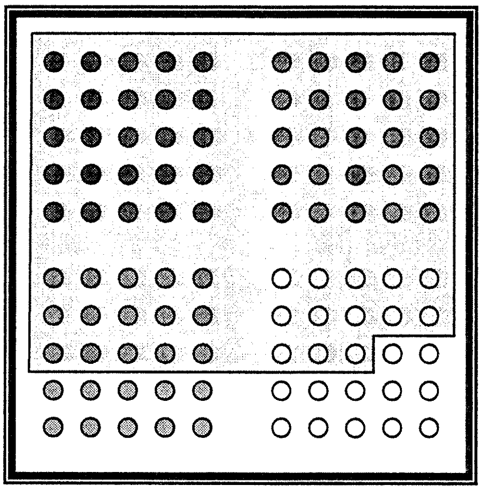
1. The Slavonic Abacus

For the spatial thinker,



represents the number 'four' in a way that the symbol '4' does not. The eye can, with practice, pick up a row or array of up to four objects 'at a glance', with no need for counting. But at an early stage children may be taught to count their fingers – to hold up four fingers, and then to count them: one, two, three, four. They may not be encouraged to see the four fingers as 'four' – as a coherent group, rather than as a row of ones.

But where it is developed, this ability to see up to four objects at a glance, without the need for counting, can form the basis of the pupil's understanding of number. Eva Grauberg, in her book *Elementary Mathematics and Language Difficulties* (1998), describes how the Slavonic abacus may be used to support the development of spatial images on which this understanding may be based. The beads on the ten by ten abacus are grouped by colour into rows and columns of five, and Grauberg shows how a 'quantity picture' of the number seventy-eight may be formed (Grauberg, op. cit., p.64):



The eye can pick up the first five rows of ten at a glance, with no need for counting. Similarly, perceiving the next two rows depends upon being able to see ● ● as 'two'. The Slavonic abacus represents single digit numbers over five as being made up of five, plus a number between one and four. Since the eye can pick out the five, then see the additional number at a glance, any number between 1 and 9 can be recognised without counting. This being the case, the tens digit in '78' is understood immediately as 'five plus two', or 'seven', tens. In the same way, the eight units are seen (*seen*, not counted) as 'five plus three'. So the array on the Slavonic abacus represents the number seventy-eight in a meaningful and memorable way, while the squiggles '78' may remain just that – arbitrary squiggles. Any two-digit number can be represented on the abacus in a way that is immediately meaningful to the spatially oriented child.

2. Spatial Multiplication

Recognising Arrays

A row of up to four beads can be seen and recognised without counting. Pupils who think spatially can learn that ○ ○ ○ or ○ ○ ○ , for example, is 'three', at least as easily – and rather more meaningfully – than they can learn that the symbol '3' means 'three'.

Having learnt to recognise O   O O   O O O   O O O O, and their column equivalents, without counting, pupils can also learn to recognise rectangular arrays up to four by four, without counting:

O O O
O O O

O O O O
O O O O
O O O O

These arrays may be put on to square cards, and pupils can learn to identify them at sight. By focusing on the spatial, rather than the symbolic, representations of the products, the interrelationships between them are brought out clearly. For example, 'four fours' is composed of 'two lots of two fours' – the array is literally made up of two pairs of two rows of four beads:

O O O O
O O O O
– – – – – – – –
O O O O
O O O O

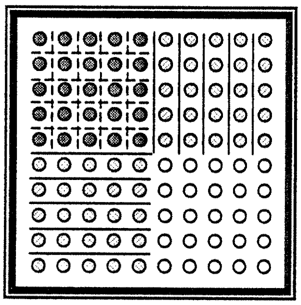
Again, multiplication is commutative – it depends which way up you hold the card whether 'six' is seen as 'three twos' or 'two threes':

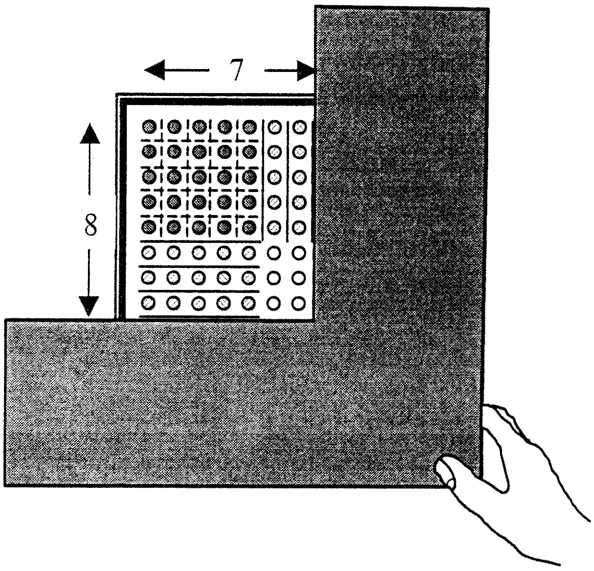
O O
O O
O O

O O O
O O O

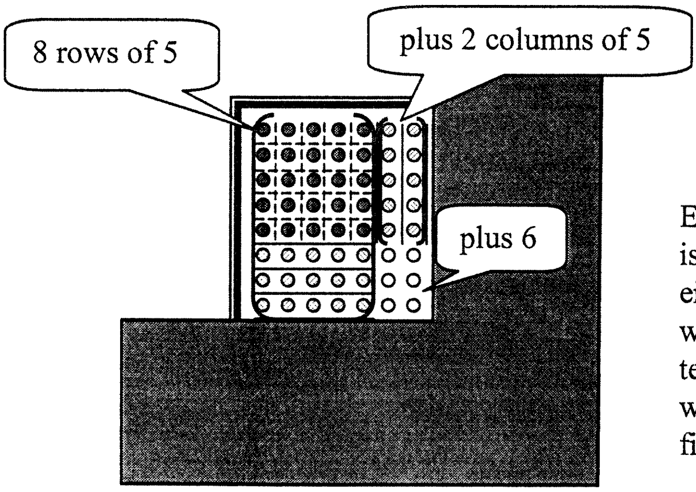
Multiplying Numbers over Five

To multiply a pair of single-digit numbers over five, the pupil can use a grid representing the Slavonic abacus, and an L-shaped shield to isolate the rectangle whose edge lengths are the numbers to be multiplied. For example, to multiply eight by seven, an eight by seven rectangle must be isolated.





The Slavonic abacus enables pupils to see numbers over five as a row of five plus a number of ones. This skill should enable them to place the shield on the grid without counting. Once the shield is in place, the product may be read off the grid.

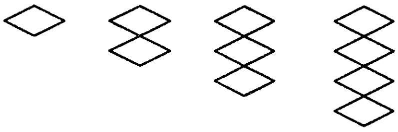


Eight times seven
is
eight rows of five, plus two columns of five, plus six,
which is
ten fives, plus six,
which is
fifty six.

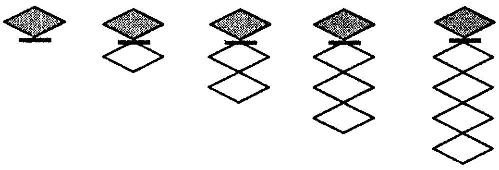
Pupils will need to use the grid in order to build up a mental image of the arrangements of the beads. With time, however, they may learn to visualise the grid, and use it flexibly to carry out the mental calculation to find the product of any pair of single digit numbers.

3. The Soroban

Another type of abacus which relies heavily on the representation of 'eight', say, as 'five plus three', is the Japanese soroban. Here, numbers up to four are represented by simple columns of beads:



Five is represented by a single darker bead, in a different position, so the numbers five to nine are:



Thus all the single digit numbers, from one to nine, are represented on the soroban by columns of beads which can be seen at a glance, without counting.

When a pair of numbers are added or subtracted on the soroban, the computation takes place through the manipulation of the beads. The operation on each number in the computation consists of a particular movement – so ‘add eight’, for example, is a ‘pinch’, to bring the five bead and three single beads into the total. If the required beads have already been used in the computation, the movement for ‘add eight’ is replaced by the movements for ‘add ten’ (flick up with the thumb), then ‘take two’ (flick down with the forefinger). After just a few hours of practice with the soroban, the instruction ‘add eight’ becomes closely identified with the movements ‘pinch’ or ‘flick thumb up, flick finger down’. In fact, the soroban frame itself becomes redundant: the user can *imagine* the soroban, and can see the beads move up and down in the mind’s eye as the fingers tremble in involuntary movement.

Thus on the soroban, the manipulation of numbers is transformed into the manipulation of objects in space. Each number and operation is represented, not by a symbol – ‘+ 8’, ‘– 12’, ‘+ 379’, and so on – but by a kinetically based pattern of movements which are applied directly to the beads on the – real or imaginary – soroban. The result of the computation lies in the final arrangement of the beads, from which the numerical answer can be read off. The symbolic squiggles which spatially biased pupils often find so difficult to grasp have no part to play in a soroban computation.

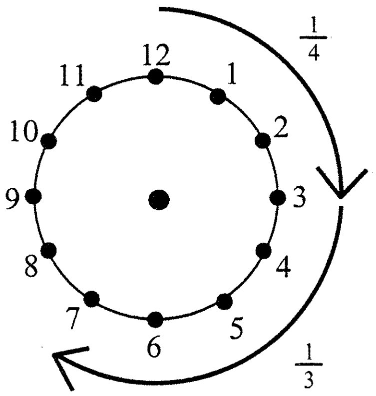
4. Manipulating Fractions

Not only the symbols for fractions, but also the rules used to manipulate them, may be more or less meaningless – and eminently forgettable – for the spatial thinker:

> *To add two fractions, you multiply the top and bottom by the same number until you get the same number on the bottom, then you add the top numbers and keep the bottom number and cancel down.*
>
> *To multiply, you multiply the two top numbers and you multiply the two bottom numbers and you cancel down.*

To divide, you turn the second fraction upside down (or is it the first? Or maybe both of them?), and then you... er...

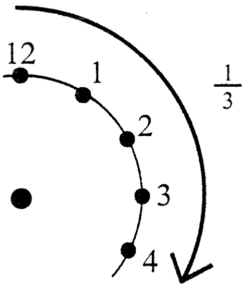
Again, what is needed is a model, a way to picture what is happening. A clock face offers a useful way to think visually about the addition and subtraction of halves, thirds, quarters, sixths and twelfths. Pupils can learn to 'see' a calculation such as $\frac{1}{4} + \frac{1}{3}$ as a movement around the clock face:

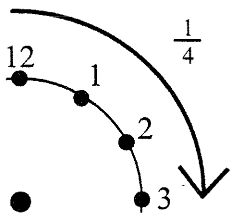


The same model is useful for a calculation involving a division, such as $\frac{1}{4} \div \frac{1}{3}$

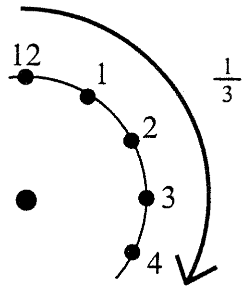
This may be restated as 'How many thirds are there in a quarter?' or

'How many of these: are there in one of these:

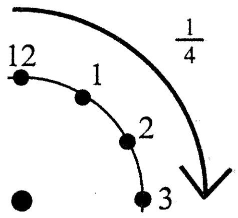




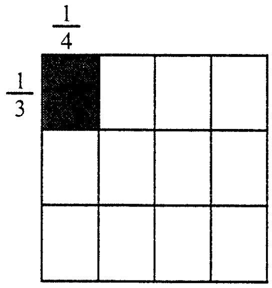
The answer is clearly less than one, since the quarter is smaller than the third. In fact, a visual inspection shows that there are three-quarters of a third in a quarter – or three-quarters of this:



in this :



The multiplication of a pair of fractions calls for a different picture – the very powerful image of multiplication as 'finding an area', which we have already used on the multiplication grid. For example, $\frac{1}{4} \times \frac{1}{3}$ may be visualised as:



5. Conclusion

Mathematics is, essentially, a very spatial subject. Like every other area of the curriculum, however, it is normally taught through the medium of print, so the pupil who can 'picture' the most complex problem effectively, but who struggles to make sense of squiggles on the page, is doomed to failure. The aim of this chapter has been to show how some of the key concepts which underlie the pupil's understanding of number can be represented in ways that make them accessible and meaningful to spatially oriented thinkers.

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CLAUSEN-MAY, T., MARKARIAN, K., POPE, S., PORTER, H. and SINCLAIR, M. (1998). *An Introduction to the Soroban*. Derby: Association of Teachers of Mathematics.

GRAUBERG, E. (1998). *Elementary Mathematics and Language Difficulties*. London: Whurr Publishers.

Address

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Association of Teachers of Mathematics

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Spatial Ability: A Handbook for Teachers

Does the way we teach match the way our pupils think?

There is increasing evidence to show that, although most teaching is based on words and depends heavily on the printed page, there are many pupils for whom words mean relatively little. For these pupils – the 'spatial thinkers' in our classrooms – thought is composed primarily of mental images.

This handbook offers teachers a straightforward introduction to some of the research which helps to explain the different ways in which our pupils think and learn. This is followed by a collection of classroom activities and ideas, for pupils of different ages and in different subject areas, which are designed to recognise and develop their spatial thinking.

The handbook raises some serious concerns, but it also offers advice, and is a valuable source of practical suggestions for teachers who are seeking to enable all of their pupils to learn effectively.

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