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CASES STUDIES OF MATHEMATICAL THINKING ABOUT AREA IN PAPUA NEW GUINEA

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This paper is a distillation of part of the ground-breaking systematic recording of measurement data from many Indigenous communities of Papua New Guinea. It focuses on area thinking and measurement. Implications for teaching measurement and making the implicit knowledge of students explicit are discussed.

CULTURAL CONTEXT AND EDUCATION REFORM

In Papua New Guinea, an educational reform program reorganised the schooling structure. One purpose of this reform was to ensure children began school in their home language. Elementary schools (pre-elementary, grades 1 and 2) were introduced so 5/6 year old children could start at a school near home in their home language. Reform syllabuses emphasise the importance of culture throughout schooling. In elementary school, in line with the syllabus Culture and Mathematics, teachers should introduce counting, arithmetic and other mathematical ideas relevant to the school’s context in the children’s home language. There is a transition to English in the second half of the third year and in early primary school (Grades 3-8).

There are over 800 languages with a diversity of patterns and types of counting (Lean, 1993; Owens, 2001). In elementary schools, counting systems are being recited but generally with English and resulting in an interesting mix of continuities and discontinuities (de Abreu, Bishop, & Presmeg, 2002; Valsiner, 2000) between vernacular counting systems and base 10 English arithmetic. Part of this relates to teachers’ limited knowledge of how their own system relates to other systems and how to use this analysis to advantage (Owens, 2000; Matang, 2005; Paraides, 2003). A detailed study on in- and out-of-school mathematics among the Oksapmin illustrates such continuities and discontinuities (Esmonde & Saxe, 2003).

One issue for the elementary and primary school teachers is an understanding of how their cultural knowledge can best be used for schooling in mathematics by making tacit knowledge explicit (Frade & Borges, 2006). This requires communication of the mathematical thinking behind activities. We set out to collect and analyse approaches to measurement for as many language groups as possible to mirror Lean’s (1993) work on counting. However, for measurement,
unlike analysing patterns for counting words, our analysis involves deeper thinking about comparisons and mathematical thinking in activities like gardening and house building.

**RESEARCH DESIGN**

Ethnographic study is appropriate to investigate “ways of acting, interacting, talking, valuing, and thinking, with associated objects, settings, and events (that impact on) … the mental networks” that constitute meaning (Gee, 1992, p. 141). Data is being collected and analysed and the analysis checked with other participants’ and communities’ data as the grounded theory develops. Our research project requires participants who are familiar with their own communities’ activities and preferably investigating their own cultural practices. We are conscious of the various relationships between ourselves, the participants and the village elders whom we interview with a participant researcher (Owens, 2006). Villages referred to in this paper come from a variety of environments (mountains, coastal areas and large valleys) and language types (Austronesian and non-Austronesian languages). For this paper, data from 16 in-depth interviews (demonstrations, discussions, and observations with some semi-structured questions) either in the village (visited by at least two researchers), at the University of Goroka or with linguists have been complemented by questionnaire and focus group data.

**RESEARCH CHALLENGES**

**Language Diversity**

The mostly oral languages are rapidly changing and being overtaken by Tok Pisin (the main creole). Linguistic ways of comparing vary (Smith, 1988). For example, there may be a limited number of comparative adjectives or very general concepts like size. Some languages may use a prefix or suffix or reduplication or similar morphology, e.g. in Dobu, pumpkin *kaprika* changes to *kapukapurika* for small pumpkin (Capell, 1943). Some languages have an adjective for a measurable attribute that is used for all objects and others have several adjectives for specific classifications e.g. round objects, flat objects, people, food, and in Korafe (Farr, linguist) *big* for fish is different to *big* for people. Two linguistic features: order of words and way of indicating emphasis can impact on discussions about measurement activities (Tupper, 2007). Metaphorical use of words makes it more complex e.g. a child is a small version, chunk, of father in Korafe. Our main communication language was Tok Pisin which has a limited vocabulary expanded by metaphors. For example, one participant researcher referred to *cm*, *m* to imply units and composite units (or at least small and large units) but not the actual size of the cultural unit. The word *leg* would be used for various uses of the leg (e.g. walking steps, metre steps, heel-to-toe steps) or part of the leg (e.g. length, or width of foot).
Cultural Values and Practices

In these Indigenous societies where marriage exchanges, compensation and many other practices require the community to participate in a display of wealth, what is valued is complex and size is not the only criterion. For the garden which is so important for a subsistence farmer, size is considered along with other attributes. Elders make decisions about how land will be distributed with varying degrees of discussion. Other considerations might be the kind of crops that best grow in a particular area, the position of the various garden plots or the use to be made of other land areas (e.g. for hunting, for food gathering, for pigs, as a barrier between tribal or clan groups, for relatives and in-laws). In addition, the elder son may receive more land. The land may be lent to a family member or passed on to the sons (examples from Matafao, Markham Valley & Kopnung, Western Highlands) or daughters.

Much of the cultural practices are not spoken about but observed. People measure by “eye” and “think in the head” and those who are competent at these tasks are involved in decisions. In order not to lose cultural context, we must ask who and how do people make decisions, what tacit knowledge is used, and how might culture and decision-making impact on the measurement process? How might this link to school mathematics and school learning?

Subsistence farmers are reliant on the environment which impacts on activities and hence on their mathematics. For example, gardening techniques in the forest differ to those in the kunai grass. Some people own both kinds of land, others do not. Rugged, steep mountains and soggy valleys change practices in other ways. Different kinds of food plants, trees, grasses, birds, and winds impact on different aspects of food and house production and time descriptions. The time of year and time of day may be described in terms of the position of the sun on the local landscape. Seas and rivers provide other mathematical activities such as canoe making, travel and fishing.

DIVERSITY OF FINDINGS FROM THE MEASUREMENT RESEARCH

Measurement Purposes

The communities place differing levels of importance on comparisons, estimations and accuracy. For some communities, marking land is carefully carried out with bright target plants that last for several generations. Natural phenomena like creeks are also used to identify a person’s land. Some people are less concerned with the measurement of the area to decide the boundary. Some groups are careful to compare heights of doors or walls with parts of the body or compare the slope of the roof with the image of other roofs (e.g. in Kopnung village). Accuracy may be decided by a group of people and/or a temporary standard (stick or rope) used by all helpers to get lengths equal (e.g. in Malalamai village). The person who owns land or builds the house may set the standard of one or more steps, arm spans or hand spans. Convenient objects
(arms, legs, rope and sticks) are used. Some lengths are kept for future reference and these may be the total length or a series of lengths marked on a stick or knotted on a rope. Estimates of amounts are made based on knowledge gained from other constructions. Some people are not too concerned about cutting the exact amount of material for frames, walls or fence posts as excess material will be used by other or more can be collected (Panim). By contrast, Kate speakers measure the floor width with rope equal to the circumference of the bamboo and they count the number of pieces that are needed. This practice helps preserve the bamboo which must be cut and carried a long distance.

**Measurement of Area**

The following provide representative cases from different geographical places in Papua New Guinea. Data from nearby villages generally confirm the summary but also indicate some variance. Some effort is made to explore the significance of these differences. For example, the need to be accurate, the nature of the ground, the availability of land, the family relationships or needs might impact on the decisions.

Around Goroka in the Eastern Highlands Province, people speak Alekano (also referred to as Gahuku-Asaro). The data were obtained from a field trip of three days to Kaveve village with demonstrations, discussions, observations and follow-up checks of our notes. Six men from other villages completed the measurement questionnaires and six schools were visited to observe and discuss elementary school teaching issues with teachers. Land area is compared by looking at it, discussing it and marking the boundary with taget plants but there is no formal measurement. When making a garden close to the house, people will decide half of it by standing in the middle of one side and deciding where the half way line should go. Half the garden is left fallow. Kaukau (sweet potato) is planted in mounds, generally with two mounds between drains. The fifth pair of mounds might be marked with a sugar cane or other plant. The various garden sizes seem to be well established in the mind suggesting that people have a good visual image of the areas involved with the garden, halves of the garden, rows of mounds, and blocks of mounds between drains.

In this area, houses are round. A pole is placed in the centre with a rope attached, people gather to decide an appropriate area for the house determining the radius. The other end of the rope is tied to the ankle of the house builder who drags his foot around to form the circle. If the house is big, then it will have a larger volume to warm with the fire and the builder needs more help from family and friends to collect materials and build. In tandem, gardens will be planted to provide food for the feast for the helpers confirming relationships between people. The roof provides triangular areas between rafters of the conical shaped roof. Each area is well pictured for the collection of kunai grass
Areas at ground, bed and ceiling level within the house are imagined in terms of space for their purpose.

In the Whagi Valley (Yu Wooi or Mid-Whagi speakers) in the Western Highlands area, the drains frequently form squares (data from three days in Kopnung village with demonstrations, discussions, and observations; and 16 measurement questionnaires from participants from other villages). The kaukau mounds are generally larger. For the men’s house, people discuss its floor plan in terms of the number of men who might sleep in it and by comparison to another house. Round numbers are used e.g. “it is for 25 men” and for the area of rooms e.g. “7 feet by 7 feet”. The square sleeping room is visualised as sleeping around seven men with the length for the man also being 7 feet. The prone position image seems as strong as the vertical. After discussion, the ground is levelled and the expected floor plan traced out on the ground. The rectangle is divided equally into three. In the middle is the area for sitting around the fire, opposite the door. The outer thirds are each divided into two squares for sleeping. Care is taken to ensure the walls are at right-angles and straight by ensuring markers are lined up. Adjustments might be made to the outer walls especially to make the ends curved.

The coastal village of Malalamai in the Madang Province is one of only two large villages speaking this language with strong customs and relationship patterns. A four day visit was made with demonstrations, discussions and observations occurring throughout the time. From other small language groups living further inland, data was subtly different. Floor areas are decided by what space the villager wants for family’s expected size and activities and the extent to which he can afford to build such a house given the amount of manpower that it requires. Plans may be modified by what is available to them in the bush. There needs to be space for sleeping, sitting to talk and eat, and cook if there is no separate cook house. People think of the floor space in terms of the number of rows of posts. These are 6, 9 or 12 posts with the base row of 3. From house to house, the space between posts is about the same. People talk of the house as half as big again (i.e., 12 post compared to 9 post) or twice the size (12 post compared to 6). In other language groups (e.g. at Panim), further inland where the winds are not so strong and the posts shorter, posts may be further apart.

Several full lengths of the roof *morata* (made from limbom timber and sewn sago leaves) determines the length of the house. They look for trees that provide sufficient sago leaves for that house, carefully selecting as the size of the leaves may vary and morata must overlap for waterproofing. Some people spread morata further apart and yet people are able to look at a pile of morata and decide if it is enough for a particular roof. In Panim the roof is exceptionally steep to make the house look nice requiring more materials. In places further inland or for smaller structures that use kunai, people estimate the area of kunai needed for the roof of a certain house. People talked of the house as requiring,
for example, 40 or 70 bundles of kunai. In Gua (Yupno language), the large round roof houses look like “stones” from a distance requiring large amounts of kunai.

In these areas, agriculture officers have encouraged cash crops like cocoa to be planted out at the vertices of tessellated triangles. Two standard bamboo lengths are used. The baseline is first marked with sticks and is parallel to the edge of the garden and equally spaced using the standard length. Then with two sticks of the same length, a second row is marked as the vertex of the equilateral triangle. These tessellated triangles form diagonal rows that can be kept clean and extended, the plants are spaced more efficiently in the sense of maximum circular space for each tree’s roots and the trees can break up the flow of water. Figure 1 illustrates this pattern. Other crops on slopes may be planted in holes placed around the roots of the hewn secondary growth trees. Yams may be carefully grown in rows but not necessarily. People have a practical idea of how big the area needs to be for the number of yams wanted in gardens near their houses for the taim hungri period when the rivers flood and they are cut off from their main gardens.

Walls of bamboo are common in many regions. The tessellated shapes, often squares, cover areas. Dried bamboo lengths that equal the length of the wall plus a bit more (a forearm length) are laid out with a small space between them and then bamboo lengths equal to the height plus a bit more are woven into them. Women (Figure 2) have traditionally made squares in their continuous figure-8 knot bilums (string bags). Nowadays women develop new designs using up to 20 needles with several colours (some repeated) and they carefully take account of the area covered by the part of each shape. For example, a hexagon may be made up of two sections knotted separately using two needles. Women count knots to assist the pattern making.

**Related Measures**

Interestingly, whenever people were asked how they measure garden areas, they talked about pacing lengths. Unlike Highlands people, coastal people tend not to pace out their gardens while groups from various places pace out the lengths for fencing. On the coast, gardens tend to be planted around tree roots and in kunai grass so that carefully spaced plants and size of land is less significant. In the highlands in particular, there are times (e.g. distribution of land between children) when the size of the garden might be considered along with other
features. Garden lengths are paced out as the width is fairly standard in each place. Widths are measured for the purpose of deciding the number of kaukau and drains.

Composite units are generally decided when a rope or stick equals a length measured by a number of steps, hand or arm spans. The space between target plants might also indicate a composite unit like 20 paces but this is rarely remarked upon.

Estimating areas involves an intuitive form of proportional reasoning. The area of kunai needed for a 6, 9, or 12 post house and the increase in floor for additional posts are examples given above. Kate people know how much area will be watered by three, four or five nodes of both a large and small diameter bamboo. Some people use the area of the pig’s foot to compare the size of pigs whereas others consider length such as how far the belly is from the ground, the length from nose to tail, or the girth.

**IDEAS FOR TEACHING IN ELEMENTARY SCHOOL**

Children could view the different gardens and skip count (2, 4, 6, 8, 10) the groups of mounds or holes if plants are placed in regular rectangular rows. The rows of plants or mounds form a composite unit. This can then be modelled in the classroom as squares, each containing a kaukau mound, to give a sense of rectangular area measure. The mapping of the triangular plantings could be illustrated by joining the dots to form tessellated equilateral triangles. Older children could look at the touching circles (representing the tree roots/branches) and compare the number of trees with those planted in rectangular rows. Material, e.g. the common lowland woven coconut frond (these only approximate a rectangular unit), could be used as an informal area unit to represent people lying down to see how big areas are for sleeping people. Similarly, people can sit on these for informal composite area units. The tessellations of woven walls and mats and bags could be used to calculate areas.

Besides exploring the gardens and making maps and models of houses for ways to compare and measure areas, teachers can prepare reading books in their own language telling a story about planting a garden or making or living in a house. Teachers do refer to standard length units that are used for a particular activity such as spaces between posts or morata, and the size of the fishing net holes for catching different types of fish (e.g. in Malalamai). The concepts of an area unit and of composite measurement units also need to be established by these activities.

Communities also need to develop a lexicon of words and grammar related to measurement (see earlier comments on language). For example, how will they select words to refer to area (not place), volume and mass, smaller and larger units (not just big and small), and how will they refer to lengths generally (cf. the English use of length for the longer side of a rectangle and as a generic
attribute). Linguistic issues can be illustrated by Korafe— the nominal word e.g. length is also the adjective long, similarly depth of the sea for deep but width has the meaning of only the one side. The word for big refers to volume. The word ai is used for pile so it is like a volume unit but they do not have a word for group unlike the neighbouring language Baraga nosi. Korafe provides comparatives for bigger, biggest etc by using suffixes.

**DEVELOPMENT OF THE CONCEPTS OF AREA AND AREA UNITS**

Frade and Borges (2006) discussed the issues of making implicit knowledge explicit. We can generalise to say that people have a sense of area (tacit knowledge) developed through sleeping, gardening and house building in particular. People are able to use this idea of area to make judgements such as the estimated amount of material needed for a house of a particular floor size. Many participant researchers referred to the length of a garden as a measure of a garden. However, people would visualise a garden by knowing its length. Some visualised the kaukau mounds, others visualised a garden with a common width. Similar comments could be made about floor plans and roof areas. The static environment provides some mathematics whereas mathematical thinking occurs during the process or activity. By making these points explicit, teachers can reduce the discontinuities in knowledge and hence build a firm basis for school mathematics.

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