Changing Our Perspective on Measurement: A Cultural Case Study

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Papua New Guinea has hundreds of languages and cultures and each group measures in different ways. This report discusses the informal measurement and contexts for measuring by a range of cultural groups as obtained from a survey. Intuitive approaches traditionally used in villages indicate an interesting use of length for deciding areas. People seem to visualise the areas and rely on lengths for comparing or counting to compare these areas. The use of informal measurement has implications for schooling in that it is a valuable place to begin measurement education rather than smaller formal units. Concepts, such as area, and the structure of measurement units, such as placing length units end to end, can be ascertained and established from these informal measures as a transition to more formal school measurement.

Students enter school with a wealth of home experiences. Teachers often make assumptions about the nature of these experiences based on their own familial situation rather than knowing what alternative experiences may be available to their students. Sensitive teachers realise there are differences when teaching students from socio-economic backgrounds or cultures that differ from their own but may not have a framework for exploring these differences or making use of these diverse experiences when teaching. Other teachers rely on the textbook to guide their teaching of a mathematics topic without realising that it might have little significance for the students. They presume mathematics is the same for all students. However, home cultural background can be very important in how and what a student learns in mathematics (D’Ambrosio & Gomes, 2006; de Abreu, Bishop, & Presmeg, 2006; Gerdes, 1996; Kaleva, 2003; Matang & Owens, 2004; Nunes, 1992). According to Bishop (1988), all cultures are involved in the mathematical activity of measuring and he showed that tertiary students from Papua New Guinean (PNG) societies thought differently about mathematics. He concluded “there is more than one way of viewing the world, the mathematician’s view is a particular one … shaped by a particular culture, it assumes many cultural ‘supports’, and increasing our own awareness of these cultural supports will improve the ways we introduce learners to the mathematician’s world” (Bishop, 1978, p. 90).

Recent studies on home-school transitions have focussed on the conflict of the school system and the socio-economically disadvantaged cultural groups (Civil & Andrade, 2006; de Abreu et al., 2006). Disassociated knowledge can be rationalised “At home I add, at school I multiply,” said Bishop’s (1978, p. 90) PNG interviewee when confronted with conflicting choices of ways of finding area in his two sociocultural contexts. Bishop interpreted the student’s explanation of pacing up the side and across the width as finding a semi-perimeter. However, the student’s rationalisation did not generate a coexistence productive of a strong understanding of area. One recent PNG study in culture and mathematics illustrated the continuities and discontinuities of out-of-school mathematics and school mathematics for counting and currency by showing a two-way influence of school and community (Esmonde & Saxe, 2004) but not as a focus of how to assist schooling.

More productive transitions are expected when teachers and students understand their cultural capital in terms that link to school mathematics. The possibilities are widened by associations that belong to another language and culture; they are curtailed by unresolved conflict (Presmeg, 2006; Valsiner, 2000). Students and teachers must recognise and value cultural mathematics for this knowledge to be related effectively in school mathematics (Gorgorió, Planas, & Vilella, 2006; Owens, 1999). The Yupiaq in Alaska have improved their performance on standard mathematics test questions from their use of cultural mathematics topics (Lipka & Adams, 2004). One cultural topic, fish racks, involved the use of measurement.

Complementarity underlying explicit cultural interaction may be dependent on cultural immersion in the first language, which is supported by schools recognising cultural ways of measuring. "(These) ways of acting, interacting, talking, valuing, and thinking, with associated objects, settings, and events (impact on) … the mental networks" that constitute meaning but can only be determined by ethnographic study (Gee, 1992, p. 141) because of their implicit manifestation (de Abreu et al., 2006; Thomas & Collier, 1997). Explicating tacit knowledge and visualisation requires careful observation, discussion, and reflection on practice (Frade & Borges, 2005). Cultural capital is a powerful tool for learning and social justice (de Abreu et al, 2006; Fowler, 1997) but it is embedded in cultural relationships. In PNG societies, respect impacts on the language of everyday activity and on communication, knowledge is embodied in actions that are often observed and not described, and certain people may have particular knowledge (Owens, 2006). Furthermore, researchers must provide educators with theory to consider how to make the tacit knowledge of the student explicit in school learning (Gee, 1992).

This paper presents recently collated data from tertiary students illustrating other important aspects of their thinking about area and clarifying the discontinuity that Bishop had observed during his visit to PNG. These data have informed our knowledge of contextual learning about area and hence our pedagogical knowledge of teaching and learning measurement, especially area.

Background on Papua New Guinea

Papua New Guinea is comprised of 800 distinct language groups living in mountainous regions, large valleys, coastal swamps, and plains, and many differently-sized islands. There are large towns with people from many language groups often communicating in the lingua franca Tok Pisin. These towns have modern buildings, simple dwellings, and self-help housing with or without basic amenities such as electricity, sewerage, and water. Most people live in rural areas in villages with bush-material housing often without piped water or electricity. Children now begin school in schools supported by the community with the government providing minimal, flexibly delivered training and salaries for teachers. These elementary schools begin in the children's home language as far as possible and gradually transfer to the English curriculum. Vernacular languages and cultures are encouraged throughout the primary school and later. These elementary schools have a syllabus called Culture and Mathematics that provides broad guidelines but because of the diversity of cultures does not give specific details. The teachers use some group work, the village as a resource and some basic equipment like a slate, an exercise book, pencil, and stones and sticks to assist with counting. Assisting the teachers and teacher educators to understand the continuities and discontinuities between cultural mathematics and western school mathematics is critical for improved education. Previous, extensive work on the diversity of counting systems by Lean (1993) has been linked recently to schooling (Matang & Owens, 2004; Owens, 2000). This study extends it for measurement.

Papua New Guinea Studies on Measurement

Earlier studies in Papua New Guinea referred mainly to Piagetian stages and in particular the time lag for conservation of quantity, length, area, volume, and mass compared to western students (Jones, 1973; Price, 1978; Shea, 1978). Prince's (1968) study of teachers college students indicated such a result. Prince (1968) commented that the rate of conceptual development was due to lack of manipulative skills, problems in logical operations, causality problems, and conceptual problems, particularly in conservation of physical quantities. However, in cross-cultural Piagetian studies, testing processes use unfamiliar circumstances and language, and schooling impacts on the formal operational level indicating the bias in the assessment processes (Dasen, 1972). However, although some of these studies were Piagetian style clinical studies as well as paper-and-pencil studies, they did not actually consider the cultural development of the students. Some mathematics tests and some of the Piagetian and spatial tests were given a cultural context for the questions but they did not consider cultural thinking. Although cultural issues were recognised by the Indigenous Mathematics Project (1979), and some continuing research by the Mathematics Education Centre at the PNG University of Technology (Philip Clarkson studied the language issues and Glen Lean carried out his now famous research on counting systems), cultural processes for measuring were not covered. Current doctoral research studies by Charly Mupe and Patricia Paraide are on their own cultural mathematics whereas Rex Matang is focussing on influences of his cultural counting on learning arithmetic strategies in school. Wilfred Kaleva (2003) and Francis Kari showed a strong interest in ethnomathematics and a need to pursue this area of research for improving mathematics education in PNG. A study of multiple systems should throw more light on the diversity of ways of thinking about measurement.

Current Knowledge about the Development of Measurement Concepts

Early psychological studies on measurement by Gal'perin and Georgiev (1960) showed that students need to learn that a length may be treated as a whole, that orientation and visual comparison, and rearrangement may be used to compare. Identification of the attribute, of units with parts, a unit's size, and the unit as a tool are important measurement knowledge. The ability to conserve, reason (Hiebert & Carpenter, 1980), and recognise the structure of repeated units (Curry, Mitchelmore, & Outhred, 2006) assists development. Willis (2005) pointed out that students and teachers may restrict their concepts and images of the abstract units for area by using concrete material tiles, and Owens and Outhred (1998) illustrated students have difficulties representing tiling of areas. From international studies, only 29% of students at the end of primary school could complete a diagram on grid paper to represent 13 square centimetres (Australian Council for Educational Research [ACER], 2002). Many students will calculate areas as a product of the length and breadth regardless of the shape being considered and many will not understand the concepts of area and an area unit (Clements, 1995; Hart, 1981; Willis, 2005). However, two separate studies have shown experiences that included both formal and informal units of measurement and self-made composite units (e.g., five paces) increased students' taken-as-shared understanding of measurement, units, and instruments (Maranhãa & Campos, 2000; Stephan & Cobb, 1998). Nevertheless, there is still a gap in our understanding of how intuitive thinking about area and home cultural experiences can enhance formal schooling. The study reported in this paper provides new insights into the diversity intuitive thinking and how people can successfully move from intuitive understandings of area to formal understandings.

The Current Study

By investigating how a range of different cultural groups think about measurement (especially of length and area), it is anticipated that our understanding of intuitive thinking about length and area will provide mathematics educators with a new perspective on learning about area and how to measure area. This knowledge will improve the teaching of area by illustrating how to bridge the intuitive and formal understandings, and the out-of-school and school views of area. This paper is based on survey data enhanced by some questioning of the participants as they completed the survey and some previously collected reports on culture and mathematics by teacher education (secondary and postgraduate primary) students at the University of Goroka, PNG. The majority of students are from the highlands region and northern mainland region (known as Momase). Most students were in their late twenties or older.

The survey was distributed either electronically or in paper copy to students. Currently 74 surveys from students from different language groups (some from the same language group) have been summarised. The surveys were introduced by explaining that the research was a joint project between the researchers from Australia and Papua New Guinea. Examples of measurement in different Pacific cultures were described briefly. The survey asked demographic questions on language, dialect, village, district, and subdistrict, and the following questions to be answered on length (including possible associations with area) and other kinds of measurement. These questions and the survey format developed after its initial use with a few students. The focus was on length and area. In addition, the authors had records from projects prepared by many students over the years linking their community and culture to secondary mathematics topics and reporting on comparisons of cultural differences in mathematics. The survey questions began with reference to western mathematics but also encouraged significant consideration of cultural mathematical activities. The questions were:

1. During which activities in your language community have you noticed people using traditional ways of measuring?
   For each activity, note what was being compared or measured? (e.g., length, area, volume (size), mass (weight), other, something specific to your community)
2. Select an activity in which people were using length.
3. Do specific people in your community carry out this measurement in certain activities?
4. Describe the processes in detail of how they compare or measure for each activity? E.g., what units do they use, what do they do with these units or tools.
5. Do people use a unit that combines smaller units? If so, how many and how do they join them? Why might this be done?
6. Do they use body parts? Explain and give an example of how the body part might be used in describing the measurement.
7. Is there a standard unit kept for comparing from one time to the next?
8. Talk about how much people think about accuracy when measuring. How do they achieve this?
9. What neighbouring language groups use this practice?
10. Is there another thing they might measure that might be closely linked to this measurement? (For example, some people associate bamboo lengths with the area of land it can water. Some people associate the plan area of a house with the needed wall area.)
11. Is there anything else that you think is important about this measurement activity?

In addition, students were asked to provide their language words for a range of words commonly used in relation to measuring such as *big, heavy, long*. They were asked to repeat these questions for one other activity involving another measurable attribute.

The data were analysed in terms of western perceptions of education in measurement (Owens & Outhred, 2006) and cultural capital (de Abreu et al., 2006).

Results

A number of students only provided language words or descriptions that were insufficient for us to analyse in terms of the measurement activity. However, these surveys did indicate that concepts related to measurement were used in their cultures.

The descriptions by 30 students from the highlands provinces indicated that paces, foot-sized steps, and ropes were commonly used for measuring lengths. A wide range of activities involved measuring lengths and some indicated links to area. These included house building, drains, and gardens but they also included smaller three-dimensional objects such as wigs in which small lengths of string and finger parts were used to ensure symmetry and a good fit on the person's head. The wig-makers provided words to indicate the finger width unit that could be used to mark off lengths on the wig.

Informal discussions with students indicated that many villages used a length measure to determine area. The students confirmed that they visualised the garden area width for the plot. One student indicated that the garden plots were generally a certain width so the total size could be determined by pacing out the lengths. Another student from a different area pointed out the garden plot was generally a fixed length as well as width and the plots would grow different vegetables. Several plots might contain one kind of plant. Another student commented that the gardens were long and thin running in long strips down the hillside. Each garden strip had a particular vegetable. Gardens owned by different people could also be compared as the widths were roughly the same. Sometimes a long rope was used to measure each of the lengths. The length of rope may or may not have been equal to a fixed number but it was common for it to equal 20 paces or arm spans as most languages have 20 cycle counting systems (without a specific word for 10, which is denoted as two fives) (Lean, 1993; Owens, 2000). In the cases where people counted paces to a certain number, marked the place, and then repeated the count, a long line for a garden would be marked off in 20 paces with a tankard plant or stick that also acted as a boundary marker (Simbu province languages, from Charly Muke and students). Twenty paces illustrated an intuitive understanding of a composite unit for measuring lengths but it also indicated a garden plot or area as western mathematics might consider an area unit like a hectare. In this way, the person was using a form of composite unit for length primarily but coincidentally marking out an area unit. The width of area unfolds in the mind as the length is paced out. The image did not appear to be that of blocks of narrow area one pace long but of the whole area determined by the counting. It is like the footballer who instinctively has an image of the size of a football field. If those fields were together, they would image the total area as units of a football field.

Volume measures in this region generally linked to feasts such as bride-price ceremonies, pig exchanges and *mumu* of large quantities of food cooked in a ground pit covered by leaves and heated by hot stones. In exchange and other recognition ceremonies, the number of pigs was important but the sizes of the pigs were also considered. This was frequently decided by the height of the pig but the girth of the pig was also considered. This was measured and compared using rope and much discussion. There was recognition of the idea of volume in taking the girth. One student indicated that this was a relatively new practice in his place. Cooking food, for example, a *mumu* in the ground requires a certain amount of water for steam and this will be determined by the size of the pit and the type of wood used to heat the stones. The amounts needed are decided by experience.

The 20 students from the coastal mainland provinces (Momase region) described how measures were used for making houses, bridges, gardens, holes, canoes, and bows and arrows. The depth of holes and heights were often found by a long cane. In some cases, marks were made on sticks or cane. These were used for smaller lengths such as canoe building. The marks were not necessarily showing a unit. They may have been developed for a particular canoe so that lengths can be assessed as equal for symmetry whereas other marks provided the necessary curvature. Further field work will assist with exploring the details of this aspect of measurement. In some cases the stick or cane was used for more than one measuring task. Some students made connections between these shorter lengths and long distances.

Other examples of length being used to determine areas included that of the round shell money, *maprik*. It was measured using a string around the circumference. It could be argued that the shells are generally of a similar shape and so the circumference, although not necessarily linearly related to area, could be used to compare the relative area (size) of shells. We also found composite units being used such as those given from the Ambulas language area. One bamboo length called, *Kama nak* is equivalent to five bamboo internodes called *ndik nak tamba*. About 5 x 7 bamboo length (that is 7 lengths of 5-internodes) is equal to one garden area or *tumbu*. The use of the multiplication sign to indicate the composite length is confusing with the use of multiplication for rectangular area. Records from Lean (1993) of languages given this name by students in the 1970s and 1980s indicated more than one kind of counting system including a (2, 5 cycle) system, that is, counting words were made up of the frame words 1, 2, and 5 only (note that counting numbers above five were built on five rather than the decimal system of 10). It would be interesting to investigate the use of seven as well as five. Our personal experience with men whose languages use a (2, 5 cycle) counting system is that they frequently stop to think after seven when asked to count. From another language, it was said that 1 bamboo stick = 10 arm spans. If so, it is difficult to visualise this length suggesting further information needs to be sought from this student or his language group. It is possible the stick was representing ten arm spans in a similar way to a stick representing 10 rather than a very long split or whole bamboo.

Measurement was linked to purpose. The data indicated that the cultural activity – bride price, canoe making, garden building, or hole making – influenced the comparison and measurement technique. The unit size, if used, was appropriate for the kind of length.

Similar information on the use of legs and hands was given by the 11 students from the Papuan regions. In the Bamu area of Western Province, the student reported “They use a long cane which has marks indicating length of different things, for example, men’s house, garden, war canoe, men's carving etc.” Previously, these people built large communal houses requiring a degree of accuracy as well as communication between a number of people. The student whose language is Vula’a (Hula) from the Central Province around Port Moresby, said, “In measuring fish they use hand span. In measuring depth of the ocean they use a long stick. In gardens they take steps of the same pace.” This quote illustrates the use of different units for different reasons.

The data given by 13 students from the New Guinea island languages covered some of the activities above like *mumu* cooking, canoe and garden making, and bride-price ceremonies but they added the use of length measurement for making fishing nets, bat nets and graters, as well as weaving and cutting up pigs. The nets had different lengths for the holes as needed. Graters are used for sago and for coconut and the spacings were carefully measured. Elaborate details of the importance of lengths of shell money *tabu* (arm span) were also discussed.

Discussion

In often subtle ways, there was variation between cultural groups. For example, for the same task of house-building, paces and foot-sized steps were used by some whereas others just compared with a rope or cane without counting units. Many places used both methods from time to time. Although terrain may have determined when measurements were taken, for example upland valleys with high rainfall required drainage, other measures were linked to marriage and other exchange ceremonies that are fairly ubiquitous but again ways of measuring and the value placed on measurements varied. These measurements were also influenced by the role that size of shell money or pigs played in the exchanges.

Lengths were often compared indirectly using a length of rope or a stick and some cultures did not use units to measure or compare. Body parts were commonly used as units. Feet and paces, arm spans, and hand spans were used extensively. Although some places did measure certain lengths with counted units, it was not always the case that the same unit was used for measuring different lengths in different activities (e.g., house and canoe). In other cases, they did use the same unit for length (pace for garden and house). Furthermore, not all language reports used more than one kind of length unit. These data would indicate that measuring more accurately was needed in only some activities. Small length units were evident in making nets and graters, wig making and canoe building. In general, these smaller units were not related to larger units as they were used in different activities (house and canoe building) whereas 20 paces may have been a length used as a composite unit for measuring gardens. Our data come from less than a hundred of the hundreds of available languages and we may find that in other groups there is more of an association of larger and smaller units.

The counting system structure sometimes influenced the composite units used in a community. For example, 20 paces were marked off or a rope used for that length. Variance and change were also recognised for the area of a net hole especially when the hole area increased in size when it was stretched out between poles or trees to catch bats.

The use of composite units arises from either the practical use of a rope or stick length, the counting system, or the natural environment such as a bamboo or stick node. Other practical considerations are also made such as the height or width of the biggest man in the village. His width was used to determine the diameter of a hole in a special door for entering the spirit house in one village whereas it was used for the height of a house in another village. There is also some evidence that the lengths used in a canoe depend on the size of the tree but are usually determined by previous constructions of canoes. Canoes for rivers are usually a single hollowed out trunk but the canoes used for the sea and large rivers are usually one-sided outrigger canoes with a sail.

Informal interviews with students on garden measuring by pacing have indicated a visualising of area that coincided with the pacing of the length. In other words, the students were not measuring area as a semi-perimeter but they determined the width and then established the area plots by counting lengths. Some visualised fixed plots by counting 20 paces and repeating this composite unit. Different places had differently sized plots and arrangements so that some formed a long line whereas others formed wider rectangles and the units formed a grid or were kept as separate plots.

The students were expressing their answers in English, which was sometimes mixed with the lingua franca Tok Pisin. This has made it difficult to be sure what students were intending if they said "leg". After the first class completed the survey, we encouraged students to be more precise in how they described their unit.

Numerous students hesitated in completing the survey as they were not sure how to explain how much the use of the eye, estimates and "logic" (as they called it) dominated the process rather than what they perceived as a western idea of exact unit.

Conclusion

These survey data have indicated that estimation is commonly used for comparing lengths and areas in different PNG cultural groups. However, it is also clear that informal units are used extensively with varying degrees of emphasis on accuracy using these measures. Making gardens and drains were the main areas for discussion, especially in the highlands. Food gathering and preparation is also an area where measurement takes place. This might be for nets or graters or for cooking-pit size and water for steam.

The idea of gardens being compared by pacing out the length and width (a semi-perimeter) (Bishop, 1978) now seems to be only part of the story. Although one student did say they did this and then gave the measures to someone else to calculate the size of the land, it would seem that in any village area, the people also consider the space taken up by the garden of a relatively standard width. The length is then used to decide how many of those garden plots will be used or compared. Garden area is only one of the variables that are important in comparing gardens. Fertility of the soil, closeness to the village and to water, natural drainage, and the direction it faces are all considered. The purpose for valuing also positions the discussion and may indicate relationships to family members. This study has begun to make the implicit and visual explicit (Frade & Borges, 2005).

The informal cultural approach to measurement allows students to grasp more easily the meaning of measurement and how units are structured (e.g., end to end when measuring length). The cultural practices have elicited the structure of the units (Curry, Mitchelmore, & Outhred, 2006). Moreover, the area unit such as the garden plot or the hole of the net is recognised even though they are counted by lengths. It is wise for a teacher to use the cultural or out-of-school experiences of students for measuring rather than textbook suggestions that may have been written in a different context emphasising calculations and giving small visuals of shapes. It is no wonder that experiences of large areas from out-of-school contexts were not related to small diagrams drawn on the board or in textbooks.

This ethnomathematics study is rich in itself in changing our perspectives on measurement in a cultural context and informs us of the importance of visualisation and out-of-school experience for learning in the classroom. It also suggests alternative ways by which we can introduce area in Australasian schools. For example, experiencing larger informal area units might assist students to recognise an area unit. These units might then be associated with sets of paces for length and then the larger areas imagined by pacing out these sets. In some schools, these might be garden plots but they are likely to be maps of a block of houses or classrooms, netball or handball courts, provide the context. Estimations of areas in terms of the larger units may take on more meaning. Informal measurements made by paces may solve problems related to determining the number of area units to fill a space like the netball court.

This research has only just tapped the potential wealth of Indigenous knowledge expected to be generated by further research in PNG. Although the western notions of units, structure of the units, and the notions of estimation, comparison, order, and size can be linked to traditional measurement systems, it is also clear that the measurement systems have their own specific non-western methods, purposes, and indeed strengths in introducing students to the idea of measurement.

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References

Australian Council for Educational Research. (2002). *Summing it up: Mathematics achievement in Australian schools in TIMMS 2002. TIMMS Australia Monograph No. 6*. Melbourne: ACER. Retrieved 10 February, 2005 http://www.acer.edu.au/research/TIMSS/documents/TIMSS_Maths.pdf

Bishop, A. (1978). Visualising and mathematics in a pre-technological culture. In E. Cohors-Fresenborg & I. Wachsmuth (Eds.), *Proceedings of the Second International Conference for the Psychology of Mathematics Education* (pp. 79-90). Osnabrück: PME.

Bishop, A. (1988). *Mathematical enculturation: A cultural perspective on mathematics education.* Dordrecht, Neterlands: Kluwer.

Civil, M., & Andrade, R. (2006). Transitions between home and school mathematics: Rays of hope amidst the passing clouds. In G. de Abreu, A. Bishop, & N. Presmeg (Eds.), *Transitions between contexts of mathematical practices* (pp. 148-168). Dordrecht, Netherlands: Kluwer.

Clements, M. (2005). The rhetoric/reality gap in school mathematics. *Reflections, 20* (1), 2–9.

Curry, M., Mitchelmore, M., & Outhred, L. (2006). Development of children's understanding of length, area, and volume measurement principles. In H. Novotná, M. Krátká, & N. Stehliková (Eds.) *Proceedings 30th annual conference of the International Group for the Psychology of Mathematics Education.* (Vol. 2, pp. 377-384). Prague: PME.

D'Ambrosio, U., & Gomes, M. (2006). D'Ambrosio on ethnomathematics*, HPM Newsletter 62,* 1-5. http://www.clab.edc.uoc.gr/hpm

Dasen, P. (1972). Cross-cultural Piagetian research: A summary. *Journal of Cross-cultural Psychology, 3*(1), 23-29.

de Abreu, G., Bishop, A., & Presmeg, N. (2006). Mathematics learners in transition. In G. de Abreu, A. Bishop, & N. Presmeg (Eds.), *Transitions between contexts of mathematical practices* (pp. 6-21). Dordrecht, Netherlands: Kluwer.

Esmonde, I., & Saxe, G. (2004). 'Cultural mathematics' in the Oksapmin curriculum: Continuities and discontinuities. *Proceedings of Sixth International Conference on Learning Sciences* (pp. 174-181) Available: http://portal.acm.org/

Fowler, B. (1997). *Pierre Bourdieu and cultural theory: Critical investigations*. London: Sage.

Frade, K., & Borges, O. (2005). The tacit-explicit dimension of the learning of mathematics: An investigation report. *International Journal of Science and Mathematics Education.* www.springerlink.com/content/t480t1v7v769u5r

Gal'perin, P., & Georgiev, L. (1960). The formation of elementary mathematical notions. In D. Henderson (Translator), *Reports of the Academy of Pedagogical Sciences of the USSR, 1,* 189-215.

Gee, J. (1992). *The social mind: language, ideology and social practice*. New York: Bergin and Garvey.

Gerdes, P. (1996). Ethnomathematics and mathematics education. In A. Bishop, K. Clements, C. Keitel, J. Kilpatrick, & C. Laborde (Eds.), *International handbook of mathematics education* (pp. 909-944). Netherlands: Kluwer.

Gorgorió, N., Planas, N., & Vilella, X. (2006). In G. de Abreu, A. Bishop, & N. Presmeg (Eds.), *Transitions between contexts of mathematical practices* (pp. 22-53). Dordrecht, Netherlands: Kluwer.

Hart, K. (1981). *Children's understanding of mathematics: 11-16.* London: Murray.

Hiebert,J., & Carpenter, T. (1980). *Information processing capacity, logical reasoning ability, and the development of measurement concepts: Working Paper No. 299*. Washington, DC: National Institute of Education.

Indigenous Mathematics Project. (1979). *PNG Journal of Education: Special Edition, 14.*

Jones, J. (1973). The concept of proportionality as a predictor of success at the University of Papua New Guinea, *UPNG Educational Research Report, No. 6.* Port Moresby: University of Papau New Guinea.

Kaleva, W. (2003). Secondary teacher beliefs and practices about mathematics in the Papua New Guinea Context. In A. Maha & T. Flaherty (Eds), *Education for the 21st century in Papua New Guinea and the South Pacific. University of Goroka. Available: http://www.uog.ac.pg/glec/Key/Kaleva/SECONDARY.htm*

Lean, G. (1993). *Counting systems of Papua New Guinea and Oceania. Doctoral dissertation, PNG University of Technology.* Retrieved 17 January, 2007. http://www.uog.ac.pg/glec/index.htm

Lipka, J., & Adams, B. (2004). *Culturally based math education as a way to improve Alaska native students' math performance.* Appalachian Collaborative Center for Learning, Working Paper No. 20. (ED484849)

Maranhãa, C., & Campos, T. (2000). Length measurement: Conventional units articulated with arbitrary ones. In T. Nakahara & M. Koyama (Eds.) *Proceedings of the 24thannualconference of the International Group for the Psychology of Mathematics Education* (Vol. 3, pp. 255-262). Hiroshima, Japan: PME.

Matang, R., & Owens, K. (2004). Rich transitions from Indigenous counting systems to English arithmetic strategies: Implications for mathematics education in Papua New Guinea. In F. Favilli (Ed.), *Ethnomathematics and mathematics education* (Proceedings of the 10th International Congress on Mathematical Education Copenhagen, Denmark, Discussion Group 15 Ethnomathematics, pp. 107-117). Pisa, Italy: Tipografia Editrice Pisana.

Nunes, T. (1992). Ethnomathematics and everyday cognition. In D. Grouws (Ed.) *Handbook of research on mathematics teaching and learning* (pp. 557-574). Toronto: Macmillan.

Owens, K. (1999). The role of culture and mathematics in a creative design activity in Papua New Guinea. In E. Ogena & E. Golla (Eds.), *8th South-East Asia Conference on Mathematics Education: Technical papers* (pp. 289-302). Manila: SouthEast Asian Mathematical Society.

Owens, K., (2000). Traditional counting systems and their relevance for elementary schools in Papua New Guinea, *PNG Journal of Education, 36*(1 & 2), 62-72.

Owens, K. (2006). Rethinking cultural mathematics. *Proceedings of Third International Conference on Ethnomathematics*, Auckland, New Zealand. http://www.math.auckland.ac.nz/~poisard/ICEm3/

Owens, K., & Outhred, L. (1998). Primary school students' visualising and understanding of tiling areas of different shapes. *Mathematics Education Research Journal, 10*(3), 28-41.

Owens, K. & Outhred, L. (2006). The complexity of learning geometry and measurement. In A. Gutiérrez & P. Boero (Eds.), *Handbook of research on the psychology of mathematics education: Past, present and future* (pp. 83-115). Rotterdam, Netherlands: Sense Publishers.

Presmeg, N. (2006). Shifts in meaning during transitions. In G. de Abreu, A. Bishop, & N. Presmeg (Eds.), *Transitions between contexts of mathematical practices* (pp. 211-227). Dordrecht, Netherlands: Kluwer.

Price, J. (1978). Conservation studies in Papua New Guinea, *International Journal of Psychology, 13*(1), 1-24.

Prince, J. (1968). The effect of western education on science conceptualisation in New Guinea. *British Journal of Educational Psychology, 38* ,64-73.

Shea, J. (1978). The study of cognitive development in The Indigenous Mathematics Project, *PNG Journal of Education, 14, Special Issue,* 85-112.

Stephan, M., & Cobb, P. (1998). The evolution of mathematical practices: How one first-grade classroom learned to measure. In A. Olivier & K. Newstead (Eds.), *Proceedings of the 22nd annual conference of the International Group for the Psychology of Mathematics Education* (Vol. 4, pp. 97-104). Stellenbosch, South Africa: PME.

Thomas, W., & Collier, V. (1997). *School effectiveness for language minority students.* Resource Collection Series No. 9. Washington, DC: George Mason University, National Clearing House for Bilingual Education.

Valsiner, J. (2000). *Culture and human development*. London: Sage.

Willis, S. (2005). Oversights and insights: Mathematics teaching and learning. In M. Coupland, J. Anderson, T. Spencer (Eds.), *Proceedings of 20th biennial conference of the Australian Association of Mathematics Education* (pp. 32-42). Adelaide: AAMT.