The Effects of Creating Rich Learning Environments for Children to Measure Mass

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This paper reports on a design experiment regarding young children's concepts of mass measurement. 119 year one and two children were interviewed using a clinical interview both before and after the teaching period comprising five lessons that offered rich learning experiences regarding concepts of mass. The results of the interviews were that the majority of these Year 1 and 2 children moved from using non-standard units to using standard units and instruments for measuring mass.

The teaching of measurement concepts is often sequenced from non-standard to standard units (see for example, Outhred & McPhail, 2000).Traditionally children explored each attribute informally long before encountering standard units or standard tools for measuring (Clements & Battista, 1986). However, more recent studies have questioned whether this sequence is the best approach (Clements, 1999; Clements & Bright, 2003). Studies of children's development in concepts of length for example, found that using standard units better supported children's development of measurement and that non-standard units could interfere with this development (Boulton-Lewis, Wilss & Mutch, 1996). Similarly, withholding standard instruments such as rulers until the end of a teaching sequence has also been questioned (Nunes, Light & Mason, 1993). Nunes et al. found that using a ruler supported children's reasoning about length and improved their performance "clearly profiting from the numerical representation available through the ruler" (p. 46). McDonough and Sullivan (2011) found that although children moved through a sequence of comparing lengths, unit iteration and use of standard units over the first three years of school, there was a great diversity at each year level and suggested that children could be introduced to standard units of length in the second year of school.

Although the design experiment reported in this paper was concerned with children's concepts of mass, the results of studies in other areas of measurement such as length are pertinent, particularly as studies regarding mass are scarce. Furthermore, it is important that research advice that children can and should move more quickly to the use of standard units and instruments in measurement of length be tested in context of mass measurement.

This study builds on earlier research (Clarke, Cheeseman, McDonough, & Clarke, 2003). In an earlier paper (Cheeseman, McDonough & Clarke, 2011) we argued that rich experiences involving measuring mass are needed, particularly at the Year 1 level where the data we reported from interviews with 479 students indicated that little progress appeared to have been made over a year. By rich mathematical learning experiences we mean those in which children are offered opportunities to engage in activities which have the potential to lead to conceptual understanding in mathematics, that challenge children to think, and foster the communication of mathematical reasoning.

The earlier paper also emphasised the importance of teachers assessing children's understandings of mass measurement and structuring learning opportunities to build on and extend those understandings. Having made these recommendations we designed the present study to further investigate the learning impacts on young children of structured opportunities to learn about mass.

Methodology

Design and Teaching Experiment

The study can be considered design research (Cobb, Confrey, DiSessa, Lehrer & Schauble, 2003). A design experiment was described by Cobb et al. as "engineering particular forms of learning and systematically studying those forms of learning within the context defined by the means of supporting them" (2003, p. 9). This research involved a classroom experiment in which the research team collaborated with a teacher who was a member of the research team to take responsibility for instruction. The research intent was to assess children's concepts of mass, "engineer" some rich experiences through one week of lessons and then re-assess the children's understanding of mass.

We chose this methodology to examine the complexity of the classroom; including the tasks and problems the children were asked to solve, the discourse, the participation in the classroom and the materials with which the children were engaged. We acknowledge that design research is a highly interventionist methodology. In this case it drew on our prior research and gave the research team control over specified learning intentions. However, we acknowledge while the central matters are able to be controlled, many of the ancillary elements of classroom conditions cannot.

Content of the Lessons

A unit of work on the topic of mass measurement was developed for Year 1 and 2 children. Five one-hour lessons were planned to replace the existing school planning in the area of mass. The lessons were designed to follow typical growth of children's concepts of measurement identified in the literature (Outhred & McPhail, 2000). Accordingly the lessons began with comparing mass and moved toward quantifying mass using standard units of measure. The essential difference here was the more rapid move toward standard units. The lessons were designed to engage the children in rich experiences including real world applications, problem solving and play-based approaches (Baroody, 2009; Copley, 2006). The following discussion gives some insight into the nature of the tasks.

The first lesson, *Party Bag Surprises*, focused on comparing and ordering. The children worked in pairs, choosing and placing objects in opaque party bags to create three bags of different masses. The masses were created and ordered by hefting, that is, by holding a bag in each hand and comparing masses. For each set of three bags, another pair of children was challenged to work out the order of the masses by hefting (without being able to see what was inside each bag). Upon the children's request, balance scales were made available for further comparison of mass. Much discussion occurred during this task. After using informal units of mass and balance scales in the second lesson, the third lesson of the sequence involved children measuring the mass of various envelopes and packages in a "Post Office". The children used interlocking plastic cubic centimetres, each identified as having a mass of one gram. The cubes were available in sticks of ten that is, as ten gram weights, and as loose single cubes. The children chose a variety of parcels and using a balance scale and the cubes, measured the weight of each parcel and labelled it with the number and "g" for grams (see Figure 1). A discussion followed about surprises the children had regarding the weight of the parcels and issues such as height, shape or size relating to mass were explored. In the following lesson children were offered a range of experiences with objects including fruit and vegetables and packaged foods, and using a selection of scales including balance scales and digital and analogue kitchen scales. During the final lesson children made their own set of weights using playdoh, with the purpose of assisting them to develop mass benchmarks.

Figure 1. Children weighing envelopes and packages using Centicubes.

Pre and Post Interview Data

Task-based interviews were used to assess children's learning before and after the teaching phase of the study. Each child was interviewed twice (see Cheeseman, McDonough & Clarke, 2011) by teachers trained in the use of the protocol. Children proceeded as long as they continued to have success with tasks. Written records were made of each child's responses for later examination and analysis. Subsequently codes were assigned to the responses to specify the growth point demonstrated by each child.

Coding Analysis

Codes were assigned independently by at least two of the authors according to the framework growth point demonstrated by success on the interview tasks. The tasks were designed to assess the milestones in young children's thinking about the measurement of mass as defined in the framework of growth points developed in the Early Numeracy Research Project (ENRP, Clarke, Cheeseman, Gervasoni, Gronn, Horne, McDonough et al., 2002), shown Table 1. The pre-and post-interview data were analysed using SPSS.

Table 1
Mass Measurement Framework (Clarke et al., 2002)

0. Not apparent
No apparent awareness of the attribute of mass and its descriptive language.
1. Awareness of the attribute of mass and use of descriptive language
Awareness of the attribute of mass and its descriptive language.
2. Comparing, ordering, & matching with the attribute of mass
Compares, orders, & matches objects by mass.
3. Quantifying mass accurately, using units and attending to measurement principles.
Uses uniform units appropriately, assigning number and unit to the measure.
4. Choosing and using standard units for estimating and measuring mass, with accuracy
Uses standard units for estimating and measuring mass, with accuracy.
5. Applying knowledge, skills and concepts of mass
Can solve a range of problems involving key concepts of mass.

Teacher-researcher Role of the Authors

The role of the authors was that of active participant-observers in each classroom. The third author, who is a practising primary school teacher, taught lessons during the teaching experiment.

Observational Data

In addition to the quantitative data, observational data were gathered by all authors to provide further insights into young children's thinking about mass measurement. Notes, photographs and audiotapes were used to document actions, comments and thoughts of children during the lessons.

Results

The data in Table 2 show that the children made substantial gains in their learning as measured by the interview results. For the Year 1 students the development in their thinking involved moving from an awareness of the attribute of mass (30%) and some comparison of masses (12%) in the initial interview, to quantifying masses (40%) and using standard units to weigh objects (53%) in the second interview.

The Year 2 students' results show similar development in mass measurement thinking. By their second interview, only 1% of the students were unable to quantify mass, whereas 33% had been unable to quantify mass initially. Further, 89% were using standard units to weigh objects in the second interview. In fact an examination of the data indicated that there was a ceiling effect in the assessment interview as the achievement of Growth Point 5: *Applying knowledge, skills and concepts of mass* was very difficult. This will be discussed later in the paper.

Table 2
Students (%) Achieving Growth Points Pre- and Post-teaching

Interview growth point	Year 1 Interview 1 Oct 2011 (n=57)	Year 1 Interview 2 Nov 2011 (n=57)	Year 2 Interview 1 Oct 2011 (n=62)	Year 2 Interview 2 Nov 2011 (n=62)
Not apparent	2	0	2	0
Awareness of attribute	30	2	15	0
Comparing masses	12	5	16	1
Quantifying masses	49	40	37	10
Using standard units	7	53	27	84
Applying knowledge	0	0	3	5

Examining the data from the original study alongside the present data reveals an interesting distribution of patterns. Table 3 shows the distribution of interview results expressed as percentages. The two sets of results with the most similar patterns are those of the Year 1 students who had been part of the teaching experiment and the Year 2 original students. So it can be seen that after an intensive week of teaching and learning about mass, the Year 1 students had a similar profile of thinking as did Year 2 students from the original (ENRP) study.

Table 3
Students (%) Achieving Mass Growth Points

Interview growth point	Year 1 Nov 2001 (n = 479)	Year 1 Interview 2 Nov 2011 (n=57)	Year 2 Nov 2001 (n = 256)	Year 2 Interview 2 Nov 2011 (n=62)
Not apparent	1	0	0	0
Awareness of attribute	2	2	0	0
Comparing masses	17	5	6	1
Quantifying masses	69	40	50	10
Using standard units	10	53	38	84
Applying knowledge	1	0	6	5

A summary of the change in growth point code from the first to the second interview is shown in Table 4. The first and most startling result to examine is the negative growth by one student. This was a student who achieved growth point 5 at the first interview and when he measured 135grams of rice and was asked, “How many more grams of rice would you need to have one kilogram?” he initially answered 965g but quickly self-corrected to 865g. At the second interview 8 weeks later he was asked the same question as the interview protocol called for students to begin the interview one step before their first error. He calculated the answer as 965g but on the second occasion he did not self-correct.

On reflection the authors believe that having the correct answer to this question as a “gatekeeper” for a growth point code of 5 *Applying knowledge, skills and concepts of mass* was too stringent a requirement. The reason being the skills required to answer the question were more about the mental computation (1000 – 135) than about measurement knowledge.

One third of the cohort of students remained at the same growth point of the mass framework after one week of teaching and learning. This is hardly surprising as a growth point in the major research project from which the framework originated; the Early Numeracy Research Project (Clarke et al., 2002) found that a growth point typically took a student about a year to achieve. The growth points were designed to be major milestones in children’s mathematical thinking.

Approximately one third (38%) of the students had developed their thinking about mass by one growth point after a week of enriching experiences. And 28% of the students made impressive learning gains of 2, 3 or 4 growth points. The mean was 1.1 growth point gain.

Table 4

Difference between 2nd and 1st Interview Results

Change in growth point from Interview 1 to Interview 2 (in growth points)	Frequency (*n*=119)	Percent
-1	1	1
0	39	33
1	45	38
2	16	13
3	16	13
4	2	2

To illustrate the growth possible from the first to the second interview, we can examine the case of Andrew, a Year 1 boy. In the first interview, Andrew could heft to compare the mass of items and was able to use the language of heavier and lighter. However, Andrew seemed uncertain about using balance scales and was unable to explain how the scales showed items were heavier or lighter. During the first lesson of the teaching week, *Party Bag Surprises* (described previously) it was noted that Andrew worked enthusiastically with his partner to discover the difference in mass of two very similar bags. This pair asked to use digital scales so they could “get a number” that would show which was heavier. During the fourth lesson, Andrew was observed persisting for some time to find the mass of one potato using balance scales and a set of mixed weights. After many minutes absorbed in this task, Andrew was able to proudly say that the potato had a mass of 275 grams. In the second interview, it was clear that Andrew had made remarkable growth over the course of the teaching week. He was able to use the balance scales to measure with informal units and could also accurately weigh objects on the balance using standard weights giving the answer in numbers and grams. Andrew demonstrated that he was beginning to understand how to use kitchen scales and could explain how the scale worked. Perhaps of most note was that Andrew, a quiet unassuming student, became one of the most enthusiastic and eager participants during the teaching week.

Discussion

The Importance of Rich Learning Opportunities

It could be argued that the reason the children in this study made such marked learning gains was that they were taught by an outstanding teacher, the third author. However, this is true for only 3/5 of the children each day. Sarah taught the lesson on three occasions with other teachers present as observers and co-teachers and those teachers then taught the lessons with the children in their classrooms. The demonstration lessons were scheduled on a rotational basis around 5 classrooms over the course of a week. An examination of the data shows that there were no differences in the outcomes for children between teaching groups.

Curriculum Expectations

The curriculum is written in broad terms with explicit curriculum statements about mass in the Measurement and Geometry strand (see Table 5) of the *Australian Curriculum* (Australian Curriculum Assessment and Reporting Authority, 2012).

The first thing to note is that there are no explicit expectations at Year 1 level in the new curriculum documents. Based on the results of this study this would seem to be an oversight by the curriculum developers. Further, the expectations of Year 2 students seem to underestimate the potential of young students to learn about standard units that measure mass.

The speed with which the children in this study adopted the language of mass measurement and facility with use of standard units for measuring mass appeared to indicate their preparedness to use such units. The traditional approach of using informal units for an extended period before the introduction of standard units is challenged by this study as the majority of the children interviewed were able to measure accurately with standard units in the final interview. During the lessons focused on informal units, children often used the language of standard units, albeit incorrectly. For example, one boy described the difference between the masses of two party bags as “just an inch”, gesturing that the difference was small. McDonald (2011) in examining the measurement concepts of young children also noted "the children show a remarkable awareness of a range of formal units" (p. 490). We agree with Copley who advises that, "teachers should not limit their expectations of young children. Providing a variety of experiences along with reflection and communication about those experiences will result in some surprising results!" (Copley, 2004, p. 2)

Table 5
Australian Curriculum: Mass Measurement

Level	Measurement and Geometry: Using units of measurement
Foundation	Use direct and indirect comparisons to decide which is longer, heavier or holds more, and explain reasoning in everyday language (ACMMG006) p. 16.
Year 1	Measure and compare the lengths and capacities of pairs of objects using uniform informal units (ACMMG019) p. 18.
Year 2	Compare masses of objects using balance scales (ACMMG038) p. 20.
`Year 3	Measure, order and compare objects using familiar metric units of length, mass and capacity (ACMMG061) p. 23.
Year 4	Use scaled instruments to measure and compare lengths, masses, capacities and temperatures (ACMMG084) p. 26.
Year 5	Choose appropriate units of measurement for length, area, volume, capacity and mass (ACMMG108) p. 29.
Year 6	Connect decimal representations to the metric system (ACMMG135)
	Convert between common metric units of length, mass and capacity (ACMMG136) p. 32.

Conclusion

In conclusion we argue that what is important is to offer young children the opportunity to engage with interesting and stimulating contexts for learning to measure mass in which the tasks connect to their lives and the mathematical potential is rich. Of course that is not to underestimate the value of challenging mathematical conversations during the conduct of the lesson (Cheeseman, 2008, 2010; Ferguson, 2012). Nor is it to underestimate the experiences with measurement that some young children bring to school (McDonald, 2011). There is an old saying that experience is the best teacher and the children in this study have shown that they certainly have learned from their rich and thought-provoking experiences with measuring mass.

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