DATA CARDS - A PILOT STUDY OF HIGHER ORDER THINKING IN STATISTICS

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Abstract
The teaching, learning and assessment of higher order thinking in statistics has become an issue for educators following the appearance of recent curriculum documents in English-speaking countries. These have included chance and data across all years of schooling and have stressed the importance of higher order thinking across all areas of the mathematics curriculum. As part of a larger study of cognitive functioning in chance and data, an interview protocol based on a set of 16 data cards was developed and trialed with Grade 6 and 9 students. It was then adapted for group work with two classes of Grade 6 students. The levels of cognitive functioning associated with the outcomes achieved by students completing the task in the two contexts will be discussed using the theoretical framework provided by the SOLO Taxonomy. The implications for classroom teaching will be explored and suggestions will be made for further research.

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Among the higher order thinking skills which are advocated in the

Chance and Data component of A National Statement on Mathematics for Australian Schools (Australian Education Council [AEC], 1991) is the ability to analyse data sets and draw inferences. This is further reinforced in Mathematics - A curriculum profile for Australian Schools (AEC, 1994) where one of the five organisers for Chance and Data is "Interpreting data". As well the Working Mathematically strand of the Profile encourages the development of characteristics which are useful in considering problem solving situations with complex data sets. These include "Investigating", "Conjecturing", "Applying and verifying" and "Working in context". Similarly, the Standards for Grades 5-8, by the National Council of Teachers of Mathematics (NCTM, 1989) in the U.S.A., include the ability to "make inferences and convincing arguments that are based on data analysis" (p. 105).

Several needs associated with the implementation of a revised mathematics curriculum in Australia prompted the pilot study presented in this report. As the recommendations for Chance and Data were made without any research on Australian students' capabilities in the area, it is necessary to explore the levels of cognitive functioning associated with outcomes of students' problem solving in Chance and Data. This report focuses primarily on higher order analysis and inference. Further, as these higher order skills are introduced in the classroom, it is necessary to develop methods of assessing them. The Data Cards activity arose in the context of a larger research study (Watson, 1992; Watson & Collis, 1993; Watson, Collis & Moritz, 1994) which is developing instruments for assessment across the Chance and Data curriculum. Finally, there will be the need in the next few years to follow the implementation of this curriculum and it is hoped that tasks devised with a firm cognitive foundation will be helpful in this context.

The theoretical model used for the study was that of Biggs and Collis (1991). Evolving from the neo-Piagetian SOLO Taxonomy (Biggs & Collis, 1982) which stressed the sensori-motor, ikonic, concrete symbolic, and formal modes of operation within which learning cycles operate, the 1991 model incorporates an acknowledgment of the existence and importance of intermodal and multimodal functioning in many types of learning experiences. This model suggests that earlier-developed modes continue to develop in parallel with later modes and provide opportunities for interaction which may facilitate intellectual functioning in general. Of particular interest here are the ikonic and concrete symbolic modes, these being associated with intuitive functioning and the symbolic learning which takes place in school and which is usually rooted in concrete materials. Results demonstrating multimodal functioning in the acquisition of understanding of fractions (Watson, Campbell & Collis, 1993) and the work of others in the field of stochastics (Berenson, Friel & Bright, 1993; Callingham, 1994; Fischbein & Gazit, 1984; Watson & Collis, 1993) lead to the belief that such functioning will also occur for concepts in statistics and probability.

In addition to multimodal functioning, Biggs and Collis (1982; 1991) argued that, within each mode, hierarchical development took place by means of a cycle of learning. This cycle had five levels: prestructural, unistructural, multistructural, relational and extended abstract - each level representing an increasing order of complexity as summarised briefly below:

(i)Prestructural responses, which represent no use of the elements required to identify the mode in question;

(ii)Unistructural responses, which represent the use of only one relevant aspect of the mode;

(iii)Multistructural responses, in which several disjoint relevant aspects are processed, usually in sequence;

(iv)Relational responses, in which an integrated understanding of the relationships between the different aspects is achieved; and

(v)Extended abstract responses, in which integration is achieved to such a degree as to enter the unistructural level of a higher mode.

Considering responses within a mode of functioning, it is the middle three types of response which are of main concern: unistructural (U), multistructural (M), and relational (R). Recent studies of mathematical understanding within the concrete symbolic mode have found two U-M-R cycles operating in connection with students' understanding of volume measurement (Campbell, Watson & Collis, 1992), fractions (Watson, Collis & Campbell, in press), and the arithmetic mean (Callingham, 1994). These cycles, which can be traced through the years of schooling for volume measurement and fractions, appear when student understanding is viewed in considerable detail and precede the progression into the formal mode of operation. Because of the nature of the statistical understanding associated with possible interpretations of the Data Cards task, it was hypothesised that more than one U-M-R cycle would be observed in the concrete symbolic responses. It was also expected that the context within which the task was set would allow ikonic responses, particularly associated with intuitive understandings. The interaction of the two modes of thinking was also of interest.

One of the ways of thinking about the relationship between ikonic and concrete symbolic functioning during problem solving is to consider the problem solving path suggested by Collis and Romberg (1991), as shown in Figure 1. This suggests that a respondent begins by choosing either an ikonic (IK) or concrete symbolic (CS) course of action. At stages B and C of the problem solving process, interaction may take place between the two modes. It is also to be noted that some ikonic functioning may potentially lead to successful problem solving, as exemplified by the “work place” mathematics described in Resnick (1987). It is of interest to see what paths in Figure 1 are utilised during problem solving requiring higher levels of statistical thinking.

Figure 1. The problem solving path (adapted from Collis & Romberg, 1991).

Procedure

The protocol for the Data Cards task was based on 16 data cards containing information about imaginary children. An example of a card is shown in Figure 2. Although fictitious, the data were devised to represent plausible values and categories of information, such as weights referenced against age-based statistical norms (National Health and Medical Research Council, 1957).

For the initial part of this pilot project, interviews from six Grade 6 students and one Grade 9 student were analysed to explore functioning in the ikonic and concrete symbolic modes and the interaction between the two modes. The students were chosen from larger groups on the basis of responses to a paper-and-pencil questionnaire; a range of students with different abilities was selected. Interviews lasted 40-50 minutes and were conducted by the first or fourth author. All interviews were video-taped and transcripts were made which were used in the analysis which follows. After being shown the cards, the seven students interviewed were asked to think of some interesting questions which could be answered using the cards, and further prompted to imagine doing a school project using them. The purpose was to explore the associations which would be suggested by the students in terms of structuring the data base. The protocol used and the complete data set are found in Appendix A.

Name: Jennifer Rado
Age: 9
Favourite activity: Board games

Eye colour: Green
Weight (kg): 33
Fast food meals per week: 4

Figure 2. Concrete materials for Data Cards interview item.

As a result of the analysis of the interview transcripts, it was decided to explore the responses of Grade 6 students working in groups on the same task but over a longer period of time. Teachers of two Grade 6 classes agreed to have their students participate in a three-lesson unit on Data Cards led by the third author. One class had had previous classroom experience with data handling (Callingham, 1993) while the other had not. To begin the first lesson, each class was introduced to ideas about looking for statistical associations, such as whether sex or age affect favourite potato chip flavour. The Data Cards were then distributed, and students were given task requirements similar to those used for individual students. Students were allowed to work in self-selected groups with the Data Cards for the remainder of the 40-minute period with little intervention. The introduction to the second period included the display of methods of presentation of data - graphs and tables - using examples unrelated to the Data Cards. Students again worked in groups to prepare posters and reports on their conclusions to present to the entire class. The third period was devoted to finishing posters and presenting group reports to the class. All sessions were video-taped and notes were taken by the first and fourth authors. A detailed discussion of the responses of the two classes and their attitudes to the Data Cards task are given elsewhere (Watson & Callingham, 1994). For the purposes of this pilot project, selected group responses will be used to illustrate the levels of cognitive functioning achieved on the task.

Hypothesised Structure

Tasks similar to the Data Cards have not previously been analysed using the SOLO model with multimodal functioning. There may be previous cycles in the concrete symbolic mode prior to the cycles of this task, a task which encourages higher level thinking in order to recognise and explore relationships between and possibly among variables on the data cards. It is the structure of the response with respect to the cycle required for the task which is being assessed. The following are two hypothesised cycles which will be of interest for drawing inferences from the data.

The first cycle is preliminary in appreciating what is involved in interpreting the information on the cards in an aggregated rather than an individual sense.

U1-The student sees cards as representing individuals, the information about them is likely to trigger off images or intuitions about the individual; but the student cannot combine information or sort cards in a meaningful way.

M1-The student sorts cards into groups by a single characteristic and describes what is found, often still using imagination in making up stories involving the information found.

R1-The student sorts cards into groups by two characteristics, describes what is found and perhaps suggests a cause, the basic ingredient for statistical inference .

After relating together the components suggested for R1, what follows is the development of a method of justifying the validity of what is suggested. This requires another cycle in the concrete symbolic mode, where students have incorporated their R1 understandings into a more compact whole which is then applied; that is, they see the idea of sorting the data and hypothesizing associations as an integrated process and then go on to the second level of looking for explanations.

It is likely that second cycle which sees the use of concrete symbolism emerge more fully will involve the use of tables or graphs of some type, or the computation of statistics.

U2-The student realises the need for an explanation or justification of observations or claims, and attempts a simple explanation relating to one aspect of the data.

M2-The student uses tables or graphs, probably in sequence, to demonstrate associations or claims.

R2-The student uses statistics (previously taught but perhaps not immediately prior to the task set) to integrate the justifications in order to demonstrate associations or claims.

The realisation of the place that lurking variables may have in explaining a cause-effect relationship may be the signalling of the unistructural level of yet another cycle, perhaps in the formal mode.

The place of the use of school-taught statistics in the cycles hypothesised above is interesting. When a task such as Data Cards does not specifically require any statistical technique, then it is the choice of application that is of interest1.

The interaction of ikonic functioning with these levels of concrete symbolic functioning will depend on students' previous experience and inclinations. It is hypothesised that intuition and imagination are likely to play a large part in early explanations. It is also likely that visualisation will combine with informal or taught techniques to produce pictorial justifications for beliefs about the association of variables.

Results of Interviews

In this section the interview transcripts for the six Grade 6 students and one Grade 9 student will be analysed with reference to the developmental model and the hypothesised response structure described above.

One student [6.4] was interested in the data set as representing individuals for whom interesting cause-effect stories could be speculated. For example, consider the following extract.

[6.4]:"OK. Um. Andrew Williams is 14, and... he's prob... he's pretty fat, or big build or tall or something, because, I reckon he's probably a bit on the chubby side though, because he likes watching TV a lot, and he eats lots of fast food meals, tons of them actually, and um..., it sounds like he doesn't get around much and do much activities."

When pressed to support a hypothesis about fast foods and TV by looking at other cards, this student again focused on a single card and created another story.

[6.4]:"No, cos they don't... cos um, Rosemary Black, 8, her favourite activity is netball, so she probably likes doing netball and things like netball which, running around a lot, and 24 is light, and she doesn't eat that much junk food because, fast food um..., she eats pretty healthy dinners, or lunch, or something... dinners, because she goes to school."

When asked to put information together the student continued to think of causes for individual behaviour.

[6.4]:"Um. Well, if you usually, um..., you can usually..., if he watches Channel 6, they usually have lots, like Kentucky Fried Chicken, and everything like that."

This student appeared to respond with strong ikonic mode support, and was classified U1 in the concrete symbolic mode because she used the individual elements of the data base to trigger off images about the character, and was unable to move beyond this conceptualisation of the problem.

Two students [6.1, 6.2] focused initially on individual aspects of the data cards, providing responses like the following.

[6.2]:"Well, Rosemary... Like if someone asked you a question, 'What's Rosemary Black's, what's her age?', you could say '8' because you'd be looking at the card here."

[6.1]:"[pause] Well their name, if anyone asked me what their name was, I'd know, and I'd know their age, I'd know their favourite activity, I'd know everything on the sheet, probably."

Further probing, however, prompted one of the students [6.2] to begin sorting by putting pairs together, but in an unsystematic fashion, e.g., some by eye colour and some by favourite activity. No conclusions could be drawn. The other student [6.1] speculated about fast food meals and weight, but had no interest in sorting the cards or providing evidence from the data cards to support the speculation. These two students were also classified U1, for while they seemed to understand the individual elements in the data base, they had no method to proceed towards finding associations. The two showed little or no ikonic support but appeared to tie themselves literally to the facts given on the individual cards (except perhaps for the speculation of 6.1).

Three other students [6.3, 6.5, 9.1] sorted the cards by age groupings, by sex or by favourite activity. Each was then asked what they might be able to tell from their groupings. The one who sorted by sex [6.5] could only describe the characteristics of the groups, for example,

[6.5]:"They either like sports, TV, or ball games,... oh there's one that's reading, ... so is that one... ...There's lots of TVs."

[6.5]:"Um. There's no football in the girls column, and there's no, um..., netball or swimming in the boys column."

The Grade 9 student had a greater repertoire of possible ways of approaching data handling.

[9.1]:"Um, you could probably do a survey, like um, draw up a graph of the different things [...] could conduct an interview, [...] Or you could see how many people like the same things [...] At a certain age,

what they like to do."
In the end a table was created as shown in Figure 3. This took considerable time for ruling and recording. When asked to summarise what could be learned from the table, the response was similar to that of Grade 6 students [6.3, 6.5] who categorised but did not write anything down on paper.
[9.1]:"Well, I'd say TV, if I had to write a conclusion about it, I'd probably put TV is the most popular favourite activity these days, and um, probably due to the TV trend as it is, and computer games and things, um, opposed to things like, um swimming, which is more of an activity sport, which is a bit... [...] it's a bit upsetting if you think that more people like to stay inside and watch television as opposed to going swimming or whatever. And um, there's only 2 for netball and 3 for football. And then there's again 3 for board games which is a more inside sort of sport."
The one who sorted by age [6.3] agreed with the prompt that perhaps as the people got older they might eat more fast foods but then presented causes from outside the data set ("have to make dinner for themselves"). Only after further prompting did he subsequently look at the data set to see if it supported the hypothesis.

SwimmingReadingFootballNetballBoard GamesTV
Dorothy
MyersJanelle
MacDonaldBrian
WongKathy
RobertsJennifer
RadoAndrew
Williams
Sally MooreAdam
HendersonRosemary
BlackAnna
SmithScott

Williams
Mary
MinskiJohn
SmithPeter
CooperSimon
Khan
David
Jones
133234

Figure 3. Student work (Grade 9) for Data Cards interview item.

These three students' responses were considered M1, as they displayed both the ability to sort the cards by one category as a method to solve the task, and also the ability to provide a descriptive account. The response of one student [6.3], who when prompted managed to extend this descriptive account to an association between variables, might be considered almost R1.

One student [6.6] sorted by favourite activities, noted the numbers in each group who were primary or high school age and then speculated about other causes for the trends found. This response was considered R1, with some ikonic support to enhance the descriptions of the discovered associations between cards.

The levels of response for this interview item are classified as in Figure 4. No responses would appear to enter the second cycle. In each case the ikonic support was of the type which uses imagination to create stories or justify opinions (this is labelled IB with reference to Figure 1).

Type of responseIkonic SupportLevel of Concrete Symbolic Response
Focused only on individual cards with imaginative speculation on cause
IB¸
Ω
After initial individual focus sorted cards but not in a systematic fashion-U1˝
Ω
After initial individual focus would only speculate about relationships in the data-Ω

˛
Sorted cards into disjoint groups and described characteristics only
IB¸
M1˝
Sorted cards into groups, created a written table of information, and gave a descriptive account-Ω

˛
Sorted cards into disjoint groups, and considered another characteristic systematically for each (descriptively)
IB
R1

Figure 4. Data Cards interview item - Multimodal functioning.

These aspects of ikonic functioning and its interaction with concrete symbolic functioning are also illustrative of the problem solving path suggested by Collis and Romberg (1991) as shown in Figure 1. This suggests that a respondent begins by following either an ikonic (IK) or concrete symbolic (CS) course of action. Some people continue down one path or the other. Consider several examples. Two students (6.5 and 9.1) chose a straight CS course of action for response. On the other hand, student 6.4 displayed a heavy dependence on imaginative functioning and, except for an initial recognition of the data as presented on a single card, could be said to follow an IK(i) path. At

both the multistructural and relational levels, students (6.3 and 6.6) used ikonic support represented by the horizontal arrows at levels B or C of Figure 1. It would appear that the responses to the interviews in this study would illustrate that the kinds of processing suggested by Collis and Romberg (1991) occur in the area of chance and data when statistical relationships are being investigated and verified.

The Grade 9 student felt that there was not enough time during the interview to find interesting questions to answer and think about how to analyse the data. This is a valid criticism of the item in this context, and it led to the trial of the Data Cards activity with two classes of Grade 6 students.

Results of class group work

The examples chosen for discussion in this section represent the entire spectrum of work presented by the two Grade 6 classes. Although all students except one worked in groups of two to five students, in one class each student produced an individual report, while in the other only one final report came from each group. In each case note will be made of the type of response which is classified. As well it should be noted that after the first lesson, the students were introduced to scattergrams and one-way and two-way tables as methods of representing data. Some students, however, preferred their own methods of representation. The use of the arithmetic mean was not suggested by the teacher. It will also be noted at what stage of the three lessons the examples presented were produced. Unless otherwise stated, each group referred to is distinct.

Some students responded at a lower level when preparing their own summaries of a group's work than the level of thinking which appeared to be present during group discussions. This was apparent from viewing the video tape. This observation supports Lamborn and Fischer's (1988) distinction between optimal and functional responses. Optimal responses represent the student's capability, which may be approached in supportive environments, while functional responses are limited by immediate task demands and lack of support.

Although many students initially looked at the cards individually, discussion with other students in groups appeared to help students move past this U1 level to at least the M1 level of classifying the data by some variable. This also may have been facilitated by the initial discussion, where the teacher emphasised finding connections in data. Hence no finished work was produced which could be classified as U1.

There were quite a few students, however, who did not move past the M1 level of sorting the data into groups by one characteristic of the data. It is likely that this was the optimal level for these students. The time available meant that it was possible to look at more than one characteristic in the same fashion. One group during the first lesson produced lists for nine different characteristics in the data: five about the expected variables and four more related to the names of the individuals. This group went on to produce higher level work in the next lesson when provided with some methods of displaying data. Several children, however, did not progress past the M1 level in their draft posters produced with the suggestions from the second lesson.

The table shown in Figure 5 illustrates the ability to cope with a single variable and summarise the information given.

Figure 5. Tables of Data Card information at the M1 level.

Groups reaching the R1 level realised that it was necessary to consider more than one characteristic of the data set at a time. Some had difficulty working out how to do this but once an idea occurred some groups realised it could be done over and over again. The lists and summaries in Figure 6 are one boy's summary of his group's finding after the second lesson. No description came out of looking at weight

and age for eye colour but he described some observations relating favourite activity and fast food consumption. This response, while appreciating the need to relate characteristics, uses totals of fast foods regardless of the number of people involved. While most summary information is concrete symbolic, occasional ikonic support is found (e.g., "The people who play netball get out and about more...").

The U2 stage did not appear in the finished products of the class group work. Perhaps because of the nature of the group work, those students who reached an appreciation of what the task was about in terms of searching for associations in the data set were able to proceed to the next level of justification (M2). This was aided by the presentation of tabular and graphical methods at the beginning of the second lesson. Certainly students were heard to discuss trends and their causes which could be suggested in the data. Statements like "the boys pig out on fast foods" or "I think TV causes people to eat fast foods" were heard and discussed. Perhaps if left on their own, some students would not have progressed past this level, but in this situation questions were asked by other students or teachers which encouraged the students to go further. Some suggestions made at this level appeared to have intuitive ikonic support in thinking up causes of associations.

Several of the groups produced quite good reports which demonstrated an M2 level ability to justify claimed associations. Three examples warrant discussion because of the differences in approach used. Two girls produced the summary shown in Figure 7 without incorporating any ideas suggested by the teacher. They had worked out their own representation at the end of the first session and preferred to stay with it. Their graphing method used the numbers on the left vertical axis to represent ages in the left and right columns and numbers of fast food meals per week in the centre two columns. Individual data points were represented for ages but the range of values was represented for fast food meals. Two associations were demonstrated for the categories of "inside" and "outside" games, one with respect to age and the other with respect to fast food meals. The repeating of the same sort of analysis and failure to go further places this as a good non-standard M2 response.

Two boys produced the final report shown in Figure 8 using a bargraph and choosing to display only one fast food datum, the largest, for each category of favourite activity. This produced a striking result which they could claim as “significant”. It was an important focus of class discussion in terms of when people or companies might like to portray such a result. The portrayal is strictly inaccurate because of the method chosen, however the level of the report is M2. The issue of error analysis at various SOLO levels is discussed elsewhere (Watson, Chick & Collis, 1988).

Figure 6. R1 Response recognising possible association of variables.

Figure 7. Original M2 graphing response.

Figure 8. M2 response with bias due to choice of data reported.

Scattergrams, histograms and tables were used to demonstrate associations related to fast food consumption. The scattergram in Figure 9 considers only weight and fast food consumption, not age. Some students plotted weight and age but did not also consider fast foods.

Figure 9. M2 response using a scattergram.

At the R2 level it would be expected that statistics would be used in an attempt to justify claims of association, perhaps means of groups or correlations. The only technique known to some of these grade 6 students was the calculation of the arithmetic mean. One group of four girls first made summary tables of all characteristics, the last being number of boys and girls. When the number of boys and girls were equal, the group wanted to compare the characteristics for them. To do so they calculated the average number of fast food meals for each sex and the average weight, producing the rough work in Figure 10, which shows how some calculations were carried out. When the final report was produced, the group used the average weights, but could not use this to draw conclusions systematically. Perhaps the group did not have enough background to go further with an approach based on average but it appears to be verging on an R2 response. Another group of boys, however, were able to piece several separate findings to draw an appropriate conclusion, as shown in Figure 11.

Figure 10. Response verging on R2, using a formal statistic.

While statisticians could easily criticise the techniques used by some groups, they are of a higher level than those achieved by the students who were interviewed individually and mark progress toward statistical understanding which requires higher level concrete symbolic functioning.

The levels of response for the Data Cards task used with Grade 6 students working in groups are given in Figure 12. The ikonic support in this situation can take two forms: imaginative or intuitive (IB), as for the students who were interviewed, or perceptual (Ic), as in the responses using visual graphical techniques for justification. With reference to Figure 1, the interaction at level B indicates the production of stories of an imaginative or intuitive nature to justify beliefs in associations or causes. The interaction at level C is indicative of the perceptual use of techniques which might be called "work place" tools by professional statisticians. Again the multimodal nature of functioning during problem solving as suggested in Figure 1 is clear.

Figure 11. R2 Response combining findings from several tables.

Type of reponseIkonic SupportLevel of Concrete Symbolic Response
Sorted cards into disjoint groups using lists-¸
Sorted cards into disjoint groups using tables/bar graphs
ICM1˝˛
Sorted cards by two characteristics using lists & descriptions of possible associations-¸
Ù
Sorted cards by two characteristics using lists & descriptions of possible associations with ikonic supportIBR1˝

˛
Discussion of the need to justify explanations suggested for observed associationsIBU2
Use of tables/graphs to support claims of association or causeICM2
Use of average to support claims of association or cause-R2

Figure 12. Data Cards group work - Multimodal functioning.

Discussion

This pilot study has used the Data Cards task in two different contexts. Its open-ended nature has created the opportunity for a wide range of creative responses at various SOLO levels and with different kinds and degrees of ikonic support. The use of different contexts has illustrated the different types of response which can be expected when students are interviewed individually or allowed to work together over a longer period with teacher-initiated intervention. The higher level responses obtained from the groups were probably promoted by teacher suggestions, but may also have resulted from the interaction among students. Fischer's work on optimal and functional performance (e.g., Lamborn & Fischer, 1988) will be given closer attention in future research in this area. This is important as the research on group work in mathematics is not unanimous in favouring group outcomes (e.g., Stacey, 1992) and further research is needed to tease out the components which are contributing to the higher response levels in this study.

This study has moved outside the questionnaire or individual interview setting used by others employing the Biggs and Collis (1982, 1991) and Collis and Romberg (1991) models to explore the nature of cognitive functioning. It has shown the theoretical models are able to be used to describe and classify responses from either individual or group work. Also the monitoring of intermediate responses through a learning sequence can assist in documenting the effect of teacher-intervention on the learning process. If raising the levels of students' cognitive functioning in academic content areas is one of the primary purposes of education, a method of documentation of such progress would be very helpful. The models employed here have the potential to be very useful in this regard. As well as making possible the categorisation of levels of functioning, the recognition of the influence of multimodal functioning may become increasingly important in an area like statistics where problems are often based in real world experiences where intuitions and perceptions often play a large part in decision making.

Open-ended tasks such as that based on Data Cards have great potential to be useful in assessing learning in the Chance and Data area of mathematics curriculum. As the higher level objectives of the curriculum are implemented, it will be necessary to offer open-ended tasks for assessment. This will be so not only at the middle school level of this pilot study, but also for students in later years of schooling. The potential for exploring many levels and different types of functioning is increased by setting tasks like "analyse this data set...", rather than "perform an hypothesis test to conclude..." Such flexibility is becoming increasingly important as students are expected to display a large range of data analysis skills. Tasks such as the Data Cards also have potential for assessment outside of formal testing situations. If group work increases in mathematics classes, tasks which can lead to project-type assessment are needed.

The use of open-ended tasks also has implications for teachers, as is seen in several of the projects based on data cards. For example, a teacher looking at the response in Figure 9 may believe that it is an incorrect response because it is not displayed in a conventional manner; rather it is a high level response using an idiosyncratic representation by a student who had not been exposed to conventional methods. Further, teachers need to be able to recognise the bias in the representation in Figure 8, and use it appropriately to provide further learning experiences. While not condemning the students' work, the opportunity should be taken to relate this work to misleading statistical representations which may be found in other contexts.

Finally the Data Cards task as used with the Grade 6 classes illustrates that the distinction between learning and assessing is becoming blurred. For these students the Data Cards lessons were a learning experience which the researchers assessed using video tapes and students' written work. Many tasks set in the future will necessarily be of this type and all aspects of the learning-assessing cycle need to be addressed when they are planned. This pilot work is thus seen to fit well with the objectives of those promoting more authentic assessment tasks in mathematics classrooms.

What may surprise some educators is the level of sophistication which was reached by some Grade 6 students during their first introduction to statistical inference. That all students did not reach a high level is not surprising. All students in the two classes, however, produced or contributed to a poster or report on the topic. The task was highly motivating for the students involved and all gained a sense of satisfaction which was demonstrated in their oral presentations. This is an important aspect of the Data Cards task: its open-ended nature did not set unrealistic expectations for some students. Other more closed methods of presentation may have done so.

Much more research is needed in the area of assessing higher order functioning in all areas of the school curriculum. As statistical techniques become necessary in other curriculum areas such as science, social studies, health and physical education, and technology, tasks similar to Data Cards may be adapted so that they can be based on content relevant to these subjects. Issues to be considered in relation to levels of performance include the influence of group dynamics and the optimal time of involvement and intervention by the teacher. It also will be of interest to monitor the increasing levels of performance as the learning experience proceeds.

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Appendix A. Data Cards Protocol and Complete Data Set.

Protocol for Data Cards interview item
Here are some cards with information on them about a group of people.
Can you tell me what the information is about for each person?
[Go through one card to be sure that they can read the data.]
What kinds of fast food have you heard of?
What sorts of questions do you think you could answer with these cards?
Is there anything interesting about them? [Look at a few and see.]
Imagine you had to do some sort of school project.
What could you think of to do as a project with the information on these cards?
If you want to, you can use these pencils and paper [graph paper].
Is there any way you could sort the cards into groups to find out something?
Do you think the groups differ in other ways?
[if necessary] Have a look at some of the other cards...
Do you think that it's true for the other people as well?
Is there any way you could put the information together to demonstrate

your suggestion?

Complete Data Set

NameAgeFavourite ActivityEye ColourWeight (kg)Fast food meals per week
David Jones8TVBlue307
Brian Wong9FootballGreen261
John Smith10FootballGreen290
Adam Henderson12FootballBlue455
Andrew Williams14TVBlue6010
Peter Cooper16Board gamesGreen542
Scott Williams17TVBlue658
Simon Khan18TVBrown7412
Rosemary Black8NetballBrown240
Jennifer Rado9Board gamesGreen334
Anna Smith11Board gamesBrown321
Kathy Roberts12NetballBrown320

Mary Minski13ReadingGreen553
Dorothy Myers15SwimmingBlue502
Sally Moore17ReadingBrown561
Janelle MacDonald18ReadingBlue664

1 An open-ended task such as Data Cards is not the same as setting a task which asks students to calculate a mean, draw a scatter plot or perform a hypothesis test. For different students in varying contexts any of these last three could be considered Rn or Un+1 for some cycle, depending on their experience.