Statistical Literacy at the School Level: What Should Students Know and Do?

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1. Environment for Statistical Literacy

Several factors contribute to the importance of students developing statistical literacy skills at the school level. First is the expectation for participation as citizens in an information and data driven age where decision-making is likely to be based on critical skills from the realms of statistical literacy. Wallman (1993) foresaw this as both a public and private issue and Gal (2002) suggested two components required of adults. One component is the ability to interpret and evaluate critically statistical information in a variety of contexts and the other is the ability to communicate this understanding in a fashion that can have an impact on decision-making. With respect to these components of adult statistical literacy, Gal also noted the need for dispositions associated with attitudes and beliefs that would motivate citizens to be critical thinkers in this arena.

To have adults meeting the goals set by Wallman (1993) and Gal (2002) it is necessary to begin at the school level. Reform to the mathematics curriculum in many countries from around 1990 (e.g., National Council of Teachers of Mathematics [NCTM], 1989; Australian Education Council [AEC], 1991), which brought topics related to statistics and probability into the school curriculum, provided a starting point for consideration of statistical literacy. Although curriculum documents focus mainly on the traditional stages in statistical investigations, they at least acknowledge the importance of critical thinking. The NCTM (1989) for example states, "A knowledge of statistics is necessary if students are to become intelligent consumers who can make critical and informed decisions" (p. 105). The topics in the data and chance part of the school mathematics curriculum, for example, sampling, graphing, data reduction and inference, form the foundation for building sophisticated thinking skills. Collectively these topics are the second factor contributing to the development of statistical literacy at school.

Out-of-school experiences, however, place basic statistical ideas in many and varied contexts. The traditional divisions of the school curriculum into different subjects, particularly at the secondary level, have worked against integrating the ideas of chance and data across the curriculum into subjects such as science, social science, or health where critical thinking can be developed in contexts that will be useful to students when they leave school. New curriculum reforms in some countries, however, are moving to more holistic and integrated approaches to the school curriculum that encourage the inclusion of quantitative literacy across the curriculum as a tool for communication and critical thinking (Department of Education Tasmania, 2002). This factor provides further impetus to the development of statistical literacy as an important contributor to the more general area of quantitative literacy (Steen, 2001).

2. Australian Research

Beginning with work in 1993 to document school students' understanding of statistical topics in the new curriculum documents (e.g., AEC, 1991), Australian research was based on longitudinal surveys and interviews exploring foundational concepts, concepts applied in media contexts, and problem solving based on concepts (Watson, 1994). Analysis of data was based mainly on two hierarchical models. One arose from cognitive psychology (Biggs & Collis, 1982) and characterised responses based on their structural complexity, the number of components of the task employed, and the recognition of contradictions should they occur. The other model was a three-tiered hierarchy of statistical literacy (Watson, 1997), beginning with understanding of basic terminology, followed by understanding of terminology in context, and then by the ability to question claims made but without appropriate statistical justification. The outcomes are illustrated in the work on students' development of understanding of sampling by Watson and Moritz (2000).

More recently item response theory has been employed with survey items coded according to the earlier criteria to suggest levels of progression with respect to understanding of variation in relation to chance and data (Watson, Kelly, Callingham, & Shaughnessy, 2003) and with respect to statistical literacy more generally (Watson & Callingham, 2003). The focus of this report is the description of six levels of appreciation of aspects of statistical literacy approaching the goal of being able to communicate critical evaluations of statistical claims made in varying contexts. Selected examples of what students are likely to show they know and can do at each level are given.

3. Six Levels of Statistical Literacy at School

Based on the tasks used in the surveys (Watson, 1994; Watson et al., 2003) analysis of responses across grades from grade 3 indicated that important contributors to improved performance across levels were increasing engagement with context, greater facility with numeracy skills, greater appreciation of variation, and deeper appreciation of the meaning of terminology associated with application of statistical concepts (e.g., sample, average, and random).

Idiosyncratic Understanding – Level 1. At this level students can do little that would satisfy a statistician. Generally their appreciation of context is non-existent, idiosyncratic, or based on personal experience, and this reveals itself particularly in relation to sampling, chance, and inference. A task to evaluate an article with a non-representative sample related to gun access in United States schools (Watson & Moritz, 2000) is likely to be answered with beliefs such as "students shouldn't have guns." Chance outcomes are likely to be suggested based on favourite colours or numbers. For many tasks related to graphing and average there is little or no evidence of engagement. Definitions of terms are unlikely to display more than tautological appreciation, whereas work with tables and pictographs suggests students can successfully read from appropriate cells, count in a one-to-one fashion, and perform simple two digit additions. Meaningful engagement is hence limited to straight-forward contexts with limited demands.

Informal Understanding – Level 2. Although engagement with tasks at this level is still likely to be colloquial, with students distracted by irrelevant features, there are times when students demonstrate appreciation of single elements of the concepts that are relevant to tasks. This is shown for example in responses to definitions, where students are likely to focus on a single feature of "sample," such as "a test," or of "average," such as "normal." In responses to tasks requiring inferences, however, they are likely to focus on story-telling based on their own personal experience or to focus on inappropriate features of a pictograph, such as pattern rather than frequency. For chance predictions justification is likely to be based on "anything can happen" and variation in repeated trials is unlikely to be to be volunteered. When explicitly asked for a surprising chance outcome, however, many can provide an appropriate one. Numeracy skills are likely to be limited to one-step table and graph calculations, involving addition or subtraction, or to an appreciation of "half" as a chance when displayed on a spinner. Appreciation of context is very limited.

Inconsistent Understanding – Level 3. Although students' responses at this level are more likely to engage with context than at the earlier levels, they are likely to be selective, often depending on a supportive format in the statement of the task. More than one feature is sometimes considered in responses but statistical ideas are likely to be expressed qualitatively rather than quantitatively. In some contexts, for example surveying classmates in a school setting, students are likely to understand the purpose of sampling but not be able to detect bias in sampling methods. In other contexts, such as selecting the more appropriate of two stacked dot (line) plots, students are likely to be able to choose the better graph but not to provide a reasonable justification for the choice. When provided with alternatives from which to choose, students are likely to identify correct interpretations of "15% chance of getting a rash" and "50 families having an average of 2.2 children." Qualitative success in chance contexts is likely to relate to identifying "more" as related to greater probability and to interpreting relative chances in relation to the conjunction of two events, again in terms of "greater" or "less" chance.

Consistent Non-critical Understanding – Level 4. At this level students are likely to display a consolidation of appreciation of various contexts without the ability to question claims of a suspicious nature. They are hence, more successful with tasks that do not require finding errors in reasoning. Multiple features of concepts are likely to be shown in giving definitions, for example describing a sample as "a small part of something bigger," an average in terms of the mean algorithm or a descriptive middle, and variation as "change like the weather varying over the period of a few days." In suggesting methods for sampling classmates in a school setting, they are likely to suggest representative methods such as "I'd pick 10 from each grade," rather than random methods. Graphing skills improve in a technical sense in that students are likely to identify highest values and ranges, and show partial success in attempting to draw an association of two variables. In choosing between two stacked dot plots, students are now likely to choose appropriately with reasoning based on the scale used. They are likely to interpret straight-forward conditional statements and order the likelihood of newspaper headlines successfully. In interpreting a pictograph, students are likely to draw inferences based on frequency but not to include an element of uncertainty.

Critical Understanding – Level 5. At this level students are likely to engage in critical analysis in both familiar and unfamiliar contexts that do not require sophisticated mathematical reasoning. They are likely to use terminology appropriately and give integrated definitions, for example of "sample" and "variation." In suggesting methods of selecting a sample of students from a school, students are likely to include both random and representative methods or two different random methods, as well as identifying bias in the methods suggested by others. Graphs drawn to show the association of two variables are likely to be acceptable and the error in a pie chart that shows 128%, identified. In relation to variation students are likely to volunteer words like "about" when making predictions and to notice change over time or mention variation explicitly when looking for unusual features of a bar chart from the media.

Critical Mathematical Understanding – Level 6. Students at this level not only display critical questioning skills in all contexts but also can employ proportional reasoning and understanding of independent events when calculating probabilities. They further realize the importance of including an aspect of uncertainty in drawing inferences expressed in tasks. The language issue is illustrated with the newspaper article reporting a non-representative sample in relation to access to guns in United States schools. At this level students recognize the problem without a hint and with specific mention of "sample" or "population" in the article. Students are likely to question the presence of an outlier in a small data set and eliminate it when calculating the mean. When asked to question a researcher reported in the media, students at this level question a cause-effect claim and often suggest the presence of a lurking variable. They are also likely to be able to interpret a misleading picto-bar graph in order to perform complicated rate calculations.

4. Implications and Future Research

Clearly Level 6 is the goal by the time students leave school but without an appreciation of the preceding levels of likely progression, it is not possible to plan experiences that will assist students to the higher levels of understanding. It is important to know the kinds of misapprehensions and partial comprehensions that develop and change over the years of school. Although it is not possible to place grade levels definitively with the levels of development observed, it should be noted that by the end of grade 10, the end of compulsory schooling, many students are not performing at the highest level described above.

One of the important findings in this research has been the influence of context in determining levels of understanding. At the first two levels students struggle with interpreting all but the most straight-forward contexts. At Levels 3 and 4, they cope with tasks that require an understanding of concepts in various settings but not the criticism of questionable claims. At the top two levels students appreciate the subtleties of context and show a propensity to question most claims that are made without proper statistical justification. Other findings with respect to specific topics in the school chance and data curriculum tend to confirm development found in other studies.

There are many possibilities for future research in association with students' development of understanding of statistical literacy while at school. Extending the survey work to include interviews will provide further evidence of students' constructed understandings. Work with sampling suggests this will be a useful approach (Watson & Moritz, 2000). As well classroom-based research including instruction specifically aimed at improving statistical literacy will be useful in determining which types of activities are most useful in this regard. Employing technology, perhaps to access media contexts or to develop familiarity with software, may prove to be an important part of instruction trialled in the classroom. Finally, it will be important to carry out research with teachers themselves to explore their understandings and help them develop the classroom strategies required to improve the levels of performance of their students.

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RÉSUMÉ

This paper describes the environment within which statistical literacy becomes a necessary part of the school curriculum. Then based on Australian research using criteria including levels of cognitive development, a hierarchy of critical statistical thinking, and item response theory, a model of the expected progression in student understanding is presented. This includes examples of student responses at various points in the progression. Implications are noted and directions for future research suggested.

Cet article décrit le milieu dans lequel la connaissance des statistiques commencent à jouer un rôle nécessaire dans le programme scolaire. Ensuite, fondé sur les recherches australiennes, on présente un modèle de la progression anticipée dans la compréhension des étudiants, où on utilise des critères, qui comprennent des niveaux de développement cognitif, une hiérarchie de réflexion critique des statistiques et l'analyse de Rasch. On donne aussi des exemples des réponses scolaires au cours de la progression. On fait attention aux implications des recherches et on propose la direction pour ces recherches à l'avenir.