CURRICULUM EXPECTATIONS FOR TEACHING SCIENCE AND STATISTICS

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This paper focuses on the curriculum links between Statistics and Science that teachers need to understand and apply in order to be effective teachers of the two fields of study. Meaningful Statistics does not exist without context, and Science is the content focus of Session 1A. Although curriculum documents differ from country to country, this paper uses extracts from The Australian Curriculum: Mathematics and the US Common Core State Standards for Mathematics and links the statistical ideas with the relevant parts of The Australian Curriculum: Science and the US Next Generation Science Standards for States, by States. Teachers of Mathematics need to be aware of the potential of Science to provide meaningful contexts within which to set statistical investigations. Similarly teachers of Science, developing methods for implementing investigations and experiments in their classrooms, need to be aware of the close ties to statistical tools for decision-making.

INTRODUCTION

Nearly 40 years ago the famous Indian statistician, Rao (1975), said, "Statistics ceases to have meaning if it is not related to any practical problem … The subject in which a decision is made is not statistics. It is botany or ecology or geology and so on" (p. 152). Although it is doubtful that Rao intended to restrict statistics to practical problems in subjects in Science, it is convenient for the purpose of this paper. The purpose is to focus on the important links between the sections of Mathematics and Science curricula that relate to investigations that require inferences to be made.

Several questions arise in exploring the links between the two subject areas. Although Rao's comment could lead directly to the search for examples of contexts from the content of Science that can produce data to which the procedures taught in the Statistics and Probability section of the Mathematics curriculum can be applied, a more fundamental question is related to how the two subject areas view a scientific inquiry and a statistical investigation. Are they the same? It is clear that statistical investigations can take place in other disciplines than Science and that scientific investigations may involve concepts that do not involve collection of the type of information that is amenable to statistical analysis. What is the intersection of Science and Statistics (within Mathematics) that teachers of Science and Mathematics should employ and exploit in their teaching? Following the exploration of this question, it is possible to suggest a few specific examples of activities.

From the field of statistics education, Holmes (1980) suggested the structure of the statistics curriculum should be laid out as data collection, data tabulation and representation, data reduction, probability, and interpretation and inference. Implicit in the structure was the proposing of a statistical question, which, acknowledging Rao (1975), would include a context. The missing element in Holmes' structure was the explicit singling out of variation as the underlying feature of data that affects every stage of a statistical investigation. Moore (1990) established the fundamental nature and importance of variation, claiming that without variation there would be no statistics. Although this claim is implicitly recognized by statisticians, it needs to be made explicit for school students. It is just as essential as is Rao's claim about context.

Following the work of Holmes, Rao, and Moore, the *Guidelines for Assessment and Instruction in Statistics Education (GAISE) Report* (Franklin et al., 2007) promote the ultimate goal of statistical literacy for all citizens. GAISE provides a framework for statistics instruction from K to 12, separating the content into three levels, A, B, and C, based on levels of prerequisite statistical literacy, rather than on grade in school. Significant in the GAISE specification of the statistical investigative process within its four components is the role of variability in the process. These are summarized in Table 1. The nature of variability across the three levels includes: measurement, natural, and induced variability at Level A; sampling variability at Level B; and variability in model fitting at Level C. GAISE is not an adopted curriculum document in either Australia or the US, but it provides an ideal with which to compare the curricula of the two countries.

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MATHEMATICS CURRICULA

In Australia, *The Australian Curriculum: Mathematics* (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2013c) splits the Statistics and Probability strand of the curriculum into two sub-strands: “Chance” and “Data Representation and Interpretation” (DR&I). Under DR&I, there are 38 descriptors across the years from Foundation (pre-Year 1) to Year 10A (advanced Year 10).[1] Many of these supply the procedures, representations and measures to be covered, e.g., pictographs, stem-and-leaf plots, means, and medians. The words “investigate” and “evaluate” are used, but the word “inference” does not appear, and nowhere is there an indication of how the components of an investigation should be put together to form a whole. The teacher is left with different components in different years as shown in Table 1. These ingredients are very useful, but “investigate” and “evaluate” do not describe the necessity to make decisions for populations based on samples, even though random samples from populations are mentioned in Year 8. The concept of informal inference (e.g., Makar & Rubin, 2009) is not included explicitly in the curriculum. Student involvement in creating and exploring data is encouraged, but few contexts are suggested.

Turning to Statistics within Mathematics in the US, the writers of the *Common Core State Standards: Mathematics* (CCSSM) (Common Core State Standards Initiative [CCSSI], 2010), did not appreciate the need to recognize the importance of Statistics and Probability until Grade 6.[2] From that grade, however, the learning curve is quite steep through the high school years. Putting aside the debates taking place in education circles about the quality, realism, implementability, and political motives of the CCSSM, and considering its content in relation to Mathematics and Science teachers and inferential decision making, several important points can be made. One is related to Rao’s (1975) call for meaningful contexts. The section on Statistics and Probability for high school begins with promise: “Decisions or predictions are often based on data – numbers in context” (p. 79). The document is, however, mainly a statement of procedures and techniques with limited examples, which requires teachers to show considerable creativity in finding contexts appropriate for extended investigations.

In relation to the learning curve from Grade 6, the first expectation to “Develop understanding of statistical variability” (p. 45) lays an excellent foundation for what comes after. The immediate introduction of histograms and box plots, however, puts tremendous pressure on students’ proportional reasoning skills, which are also being introduced in Grade 6 (p. 42) and not extended until Grade 7 (p. 48). Grade 7 for Statistics and Probability then moves immediately into “Use random sampling to draw inferences about a population” and “Draw informal comparative inferences about two populations” (p. 50). The importance of representativeness of samples is mentioned but not other methods of collecting data or asking students to trial different methods and devise their own survey questions and test them. Using measures of center and variability to draw informal inferences is required, but it is not clear which measures these are or what criteria students might use to make decisions. In Grade 8, the CCSSM only addresses “Investigating patterns of association in bivariate data” (p. 56). This includes constructing and interpreting scatter plots, linear models, and two-way tables. The Standards for Mathematical Practice within the CCSSM add a dimension of process and proficiency to the procedure and understanding dimension of the Standards for Content. These include problem solving and reasoning (both abstract and quantitative). Constructing arguments and critiquing the reasoning of others, modeling with Mathematics, and using appropriate tools strategically (CCSSI, 2010, p. 6-7) are particularly appropriate for statistical investigations, as well as the reference to a parallel visual model on modeling (p. 72).

The high school section of the CCSSM on Statistics and Probability covers the three grades, 9 to 12, in one section; hence it is difficult to separate suggestions across the three years and to plan developmental learning sequences. As well as focusing on interpreting categorical and numerical data, the CCSSM asks students to make inferences and justify conclusions, including the use of resampling procedures (p. 82). Although light on detail at this level, the expectations for informal inference and its required antecedents are stronger in the US, than the Australian, curriculum.

A comparison of examples from the US and Australian documents is shown in Table 1 in relation to the GAISE framework for an investigation. What appear to be missing from the US

CCSSM are opportunities for students to initiate their own investigations. In neither country is there an explicit goal for students to carry out a complete statistical investigation from beginning to end each year. Although the CCSSM progresses further in its expectations for inference before the senior years than the Australian curriculum, its approach is not developmental, leaving teachers a big task in ensuring prerequisite understandings are achieved. Help in compensating for the gaps, however, is provided by the *Progressions Documents for the Common Core Math Standards* (The Common Core Standards Writing Team, 2011).

Table 1. The GAISE Framework of the statistical investigative process (Franklin et al., 2007, p. 15-16) with detailed examples from the Australian and US curriculum documents

GAISE Component	Australia	United States
I. Formulate Questions → clarify the problem at hand → formulate one (or more) questions that can be answered with data → anticipate variability	Choose simple questions and gather responses (Year 1) Pose questions … (Year 5) Identify and investigate issues involving numerical data collected from primary and secondary sources (Year 7)	Recognize a statistical question as one that anticipates variability (Grade 6) Investigate patterns of association in bivariate data (Grade 8)
II. Collect Data → design a plan to collect appropriate data → employ the plan to collect the data → designing for variability	Collect, check and classify data (Year 2) … collect categorical or numerical data by observation or survey (Year 5) Investigate techniques for collecting data, including census, sampling and observation (Year 8)	Use random sampling to draw inferences about a population (Grade 7) Make inferences and justify conclusions from sample surveys, experiments, and observational studies (HS)
III. Analyze Data → select appropriate graphical and numerical methods → use these methods to analyze the data → accounting for variability in distributions	Represent data with objects and drawings where one object or drawing represents one data value (Year 1) Evaluate the effectiveness of different displays in illustrating data features including variability (Year 4) Calculate mean, median, mode and range for sets of data. Interpret these statistics in the context of data (Year 7) Investigate the effect of individual data values, including outliers, on the mean and median (Year 8)	Display numerical data in plots on a number line, including dot plots, histograms, and box plots (Grade 6) Recognize that a measure of center for a numerical data set summarizes all of its values with a single number, while a measure of variation describes how its values vary with a single number (Grade 6)
IV. Interpret Results → interpret the analysis → relate the interpretation to the original question → allowing for variability beyond the data	Interpret secondary data presented in digital media and elsewhere (Year 6) Evaluate statistical reports in the media and other places by linking claims to displays, statistics and representative data (Year 10)	Make inferences and justify conclusions from sample surveys, experiments, and observational studies (HS)

SCIENCE CURRICULA

The Australian Curriculum: Science (ACARA, 2013d), includes three interrelated strands: Science Understanding, Science as a Human Endeavour, and Science Inquiry Skills. The first encompasses Biological sciences, Chemical sciences, Earth and space sciences, and Physical sciences. The other two sub-strands are less detailed and whereas the Science Understanding strand is detailed explicitly for 11 years (Foundation to Year 10), they are described in two-year intervals. Of particular interest here is the Science Inquiry Skills sub-strand, which has five components: Questioning and predicting, Planning and conducting, Processing and analyzing data and information, Evaluating, and Communicating. The descriptors and elaborations for these components are structured in a way that demonstrates the nature of both a scientific inquiry and a statistical investigation. Under Processing and analyzing data and information, there are many general references to representations, but no mention of measures of center or variation. Under Evaluating for Year 9-10, however, there is an encouraging reference to "identifying sources of uncertainty and possible alternative explanations" (ACARA, 2013d, p. 99). Nowhere in *The Australian Curriculum: Mathematics* (ACARA, 2013c) is such a specific sequence presented for carrying out a statistical investigation. In the Statistics and Probability strand of the Mathematics curriculum, the individual ingredients in the process are described across the years, along with specific procedures for producing the ingredients, such as various kinds of graphs, specific measures of center, and measures of variation. It is possible to claim that the Mathematics curriculum provides the details for carrying out the type of statistical analyses required to validate a statistical or scientific investigation, while in some instances the details appear to be taken for granted in the Science curriculum.

In the US, the *Next Generation Science Standards: For States, by States* (NGSS) (National Research Council, 2013) were developed in collaboration with 26 states, involving a 41-member writing team, in order to add explicit standards to *A Framework for K-12 Science Education: Crosscutting, Concepts, and Core Ideas* (National Research Council, 2012). The content in the NGSS is organized in several ways, including by the three Dimensions of the *K-12 Framework*: (i) Science and Engineering Practices, (ii) Disciplinary Core Ideas, and (iii) Crosscutting Concepts. Significant for this paper is the section on Science and Engineering Practices, which, in the *K-12 Framework*, outlines eight practices to be essential elements of the Science and Engineering curriculum. These are listed in Table 2, in comparison with the Inquiry Skills in the *Australian Curriculum: Science* and the GAISE framework.

Table 2. Comparison of essential elements of Science Inquiry in the US *Framework for K-12 Science Education* and *The Australian Curriculum: Science* with GAISE

GAISE	US (National Research Council, 2012, p. 49) Science and Engineering Practices	Australia Science Inquiry Skills
I. Formulate Questions	• Asking questions (for Science) and defining problems (for Engineering)	Questioning and prediction
II. Collect Data	• Developing and using models • Planning and carrying out investigations	Planning and conducting
III. Analyze Data	• Analyzing and interpreting data • Using Mathematics and computational thinking	Processing and analyzing data and information
IV. Interpret Results	• Constructing explanations (for Science) and designing solutions (for Engineering) • Engaging in argument from evidence • Obtaining, evaluating, and communicating information	Evaluating Communicating

The US *K-12 Framework* not only prescribes the major competencies students should have by the end of Grade 12, but also outlines the progression through the preceding grades to reach the goals in Grade 12. Although not detailed, the progressions reflect the sort of understandings that are suggested be developed more specifically in the NGSS. At each grade level the NGSS presents ideas across the four core disciplines (Physical sciences, Life sciences, Earth and space sciences, and Engineering, technology, and applications of Science). In Grade 3, for example, ideas are related to Motion and Stability, From Molecules to Organisms, Ecosystems, Heredity, Biological Evolution, Earth's systems, and Earth and Human Activity. As well as links to the three Dimensions from the *K-12 Framework*, the NGSS adds links to the CCSSI links to Literacy Standards and the CCSSI Mathematics Standards. Although many of the standards from the CCSSM are noted in the document, of interest are the topics that provide contexts for the development of standards related to Statistics and Probability. At the middle school level, topics potentially providing data for analysis include Chemical reactions; Growth, development and reproduction of organisations; Independent relationships in ecosystems; and Engineering design.

EXAMPLES LINKING SCIENCE AND STATISTICS FOR TEACHERS

There is convincing evidence that Science teachers have a model for inquiry that mirrors that of a statistical investigation. The need is to make them aware of this close connection when they are carrying out Science investigations that involve data suitable for statistical analysis. GAISE gives one such example for Level A in an experiment growing beans in two different environments (Franklin et al., 2007, p. 28). Elementary teachers teaching across the curriculum should be aware of such opportunities. A detailed example for middle school is given by NGSS for Energy. In applying scientific principles to design, construct, and test a device that maximizes thermal energy transfer, students use a scatter plot showing the temperature change in water versus the mass of ice added (National Research Council, 2013, Appendix L, p. 23). Beyond using the scatter plot, however, the teacher needs to emphasize the variation shown in the data, and how this affects the certainty with which the students' report their conclusions in relation to thermal energy transfer.

In the NGSS at the middle school level, the links to the CCSSM are to Grades 6 and 7. These relate to understanding "that a set of data collected to answer a statistical question has a distribution which can be described by its center, spread, and overall shape" (6.SP.A.2, p. 45), to displaying "numerical data in plots on a number line, including dot plots, histograms and box plots" (6.SP.B.4, p. 45), to summarizing "numerical data sets in relation to their context" (6.SP.B.5, p. 45), and to investigating "chance processes and developing, using, and evaluating probability models" (7.SP, pp. 50-51). At the high school level, topics include Chemical reactions, Independent relationships in ecosystems, and Forces and interactions. The associated links in the CCSSM relate to the same content for data handling as for the middle school level, including representing data (ID.A1, p. 81), understanding "statistics as a process for making inferences about population parameters based on a random sample from that population" (IC.A.1, p. 81), and evaluating "reports based on data" (IC.B.6, p. 82). These links to Statistics and Probability from the NGSS are encouraging but lead to the question of whether there may be missed opportunities for links when students are carrying out experiments in Science and need to compare experimental and control groups. This context is likely to be where the CCSSM can be of assistance, for example in using simulations to decide if differences between parameters are significant (IC.B.5, p. 82).

An initiative of the Australian Academy of Science (AAS) has attempted to meet the requirements of *The Australian Curriculum: Science* (ACARA, 2013d) as well those of *The Australian Curriculum: English* (ACARA, 2013b) in a project called *Primary Connections: Linking Science with Literacy* (AAS, 2011). From the Foundation Year to Year 6, books have been written across the four content areas of the Science Curriculum: Biological, Chemical, Physical, and Earth and space sciences. Not only are links provided to the English curriculum, but also to the Mathematics Curriculum, and more broadly across the curriculum (ACARA, 2013a). Both the links to Mathematics and the links to the more general capability of Numeracy point to the use of content from Statistics and Probability in carrying out investigations. The actual direct inclusion of DR&I elements is, however, quite varied. As an example, *Earthquake explorers Year 6* (AAS, 2012) from the *Primary Connections* series, claims (p. 7) to align with DR&I element, "interpret and compare a range of data displays …" in three of the seven lessons. In the second lesson students are introduced to Richter scale numbers in a table. In the fifth, students are given 30 earthquake magnitudes for different countries around and including Australia and asked to plot and compare the frequencies of different magnitudes. In the sixth, students create a seismometer by jiggling a table, but there is no explicit link for the teacher to emphasize that this is a graphical representation.

CONCLUSION

Although not all aspects of relating statistics investigations to Science inquiry can be covered in this paper, the ground is laid for a more comprehensive linking of curriculum documents and examples that teachers can use in the classroom. The Australian and US curriculum documents for statistics provide interesting contrasts. In Australia the content is developmental, covering all years, whereas in the US, content starts at Grade 6 and is outcome-oriented. The US CCSSM puts stronger emphasis on context and variation and introduces inference from Grade 7, whereas Australia does not use the word inference at all. Neither country provides an explicit model for students to follow in carrying out an investigation. In both countries Science curricula provide a model for a Science inquiry similar to that of GAISE but are less specific on the specific tools, processes, and strategies that can be useful when analyzing quantitative data. It appears that both countries and both subjects can learn from each other.

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[1]There are various units on Statistics at the senior secondary level in draft curricula, including one on statistical inference, but these are not official and not discussed here.
[2]In line with the conventions of the two countries, "grade" is used for US curricula and "year" for Australian curricula.

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