Practicing Statistics in Year 4

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This study reports on the capabilities of 53 Year 4 students as they completed the final stages of their first complete statistical investigation. In the context of becoming acquainted with students in a sister school in another city, students in both schools wrote and refined questions, which were answered by all students in an on-line survey. Using data from both schools, students chose at least one question to analyse and present their findings comparing the two cities and/or groups of students. Of interest are the representations created for the questions chosen, the conclusions drawn, the variation observed, the certainty about the conclusion, and the comments about what had been learned about writing survey questions.

In today's world of Big Data statistics educators face the task of preparing statistically literate citizens, as well as inspiring some to become professional statisticians. For some time (e.g., Wallman, 1993) there have been calls to recognise the need for a statistically literate population to make meaningful decisions, both personally, and in society. Gal (2002) extended the requirement to include the ability to communicate concerns about suspicious claims. At the school level, Watson (2006) suggested that for judging a particular claim, students need to know the terminology employed, understand how it is used in the context of the claim, and have the critical thinking skills to judge the merit of claims.

A question for educators in schools is, "how do we help students develop the skills and understanding needed to become statistically literate?" The answer from the American Statistical Association (ASA) is found in the *Guidelines for Assessment and Instruction in Statistics Education (GAISE) Report* (Franklin et al., 2007). *GAISE* outlines the steps in "statistical problem-solving" in such a way that students learn the *Practice of Statistics* (Moore & McCabe, 1989). As Moore and McCabe claim, "Statistics in practice is concerned with gaining understanding from data; it is focused on problem-solving rather than on methods…" (p. xi). *GAISE* also recognises that variation is the underlying phenomenon at every step of the practice: (i) Formulate Questions, anticipating variability, (ii) Collect Data, acknowledging variability, (iii) Analyse Data, accounting for variability, and (iv) Interpret results, allowing for variability. The aim is for students to use data to make informal inferences for populations, analysing the evidence they have from samples, acknowledging uncertainty (Makar & Rubin, 2009).

As well as the general need for a statistically literate population, the growing recognition of the importance of STEM (Science, Technology, Engineering and Mathematics) fields for solving a nation's economic and environmental problems (e.g., Office of the Chief Scientist, 2013), combined with the emergence of the field of Data Science itself (Finzer, 2013), increases pressure to employ more professional statisticians. The ASA (2017) claims that the expected employment growth for statisticians in the United States between 2014 and 2024 is 34%, compared with 7% for the average of all occupations. In Australia and New Zealand, it appears "the shortage of statisticians is a worsening problem" (Cameron, Iosua, Parry, Richards, & Jaye, 2017, p. 367). These imperatives motivate activities that help students develop the skills to be able to engage in all of the steps of the practice of statistics, thereby, engaging in the work of statisticians.

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Background

Research that reports student outcomes and capabilities in relation to working through all of the steps of the practice of statistics is scant. Of particular relevance, is a study conducted by Paparistodemou and Meletiou-Mavrotheris (2008), who worked with Year 3 students in Cyprus to introduce informal inference with data generated from a survey where they asked simple questions of classmates. The young students in that study demonstrated their capacity to draw conclusions based on the data and the situation within which the data were collected, relate the conclusions to a larger population, and identify the uncertainty associated with the conclusions. Later the researchers tested a hypothetical learning trajectory based on these results with Year 6 students to illustrate the feasibility of primary children being able to undertake the practice of statistics. This time students asked questions about eating habits. The authors documented six ways in which most students improved their reasoning about samples and sampling in the context of drawing conclusions, including the importance of sample size, the need to avoid sample bias, and the opportunity to increase representativeness with stratification (Meletiou-Mavrotheris & Paparistodemou, 2015). The contexts chosen by the researchers and subsequently the questions chosen by the students were based in the social sciences.

Watson and English (2015, 2018), however, chose STEM-related contexts when they worked with students in Years 5 and 6 to demonstrate the students' capacity for carrying out the practice of statistics with authentic data. First, in Year 5, students considered the question, "Are we environmentally friendly?", with each student deciding the percentage of "yes" responses to five sub-questions about their habits with respect to sustainability that would be required to answer the main question in the affirmative. The students collected and analysed data first for their class and then for Australia using samples from an Australian Bureau of Statistics (ABS) "population" of 1300 Year 5 students. In Year 6, students were shown a claim in the media that people with brown eyes had faster reaction times than people with eyes of other colours. The students' task was to explore this claim with data from their class and then again with random samples from an ABS "population" of 1786 Year 6 students, using the same on-line reaction timer. Through these activities and others, students demonstrated increased ability to carry out the practice of statistics, as well as increased critical thinking in other statistical contexts, shown in longitudinal statistical literacy surveys carried out across the larger study (Watson, Callingham, & English, 2017). In these two activities, the questions posed, the first step in the practice of statistics, were determined by external sources, not by the students themselves.

Although it is important for students to investigate questions raised in wider social contexts, the purpose of the activity reported here was to return to a relatively general context in which students could pose a wide range of questions of interest to themselves to investigate. After completing the practice of statistics, by analysing and interpreting data generated from questions they themselves posed, they could also be asked to reflect on their learning about posing questions.

Research Approach

The activity reported here was the third, in term 3 of Year 4, as part of a longitudinal project that followed the progress of students from mid-way through Year 3 to the end of Year 6. For the students in the project, the aim was to build and reinforce the development of understanding and capability related to the practice of statistics through investigations embedded within STEM contexts. A design-based research approach (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003) was adopted that used results from earlier activities to inform the implementation of teaching interventions as the project progressed.

In Year 3, the essential importance of variation in all contexts and for applying statistics was emphasised when students created "licorice" sticks two ways: by hand and by "machine" (Watson, Fitzallen, English, & Wright, 2019). Students then encountered the context of heat transfer, learning new ways to represent and analyse data (Fitzallen, Watson, & Wright, 2017; Fitzallen, Wright, Watson, & Duncan, 2016). In the third activity, described here, the students had active involvement in all stages of the practice of statistics. It allowed them to pose and refine their own questions to collect data, to compare results and to draw conclusions about students' activities in the context of the two cities. The initial part of the activity, posing and refining the student questions, to be administered via an on-line survey, is described in English, Watson, and Fitzallen (2017). This paper reports on the way in which the students in one school analysed and interpreted the data generated from the survey and subsequently, reflected on the process.

Participants

Year 4 students from two parochial suburban schools in two Australian cities completed the activity. All 55 students present in two classes at one of the schools (City A) took part in the activity. Data are reported on the 53 students from that school whose parents consented to the collection of data for them. The data are deidentified and reported using unique codes for each student. The average age of participants was 10.0 years (range 9.1 years to 10.7 years) and the gender split was 60% male and 40% female. The project had ethics approval from the Tasmania Social Sciences Human Research Ethics Committee (H0015039).

Implementation

The activity involved the students from both schools posing and refining questions, which were used to develop a survey to collect data about the students' activities and their environment in both cities (English et al., 2017). After introducing themselves to the students in the other city through short biographies, students individually posed the questions they wanted answered. The questions were then refined by students to eliminate non-statistical questions and each class decided which questions they wanted to include in the survey. After a discussion of the part played by technology in collecting and compiling the data, the students from both schools completed the survey on-line. The survey contained 22 questions: 7 numerical (e.g., "How many hours do you spend doing sport each week in summer?"), 4 multiple choice (e.g., "When is the best time of year to visit your city? a) Summer, b) Autumn, c) Winter, d) Spring"), 6 text box (e.g., "What do you love to do the most with your family on a sunny day?"), 1 yes/no ("Do you get homework?" □ Yes □ No); 3 sliding scale (e.g., "On a scale of 1 to 10, how much do you like visiting your botanical gardens?"); and 1 ranked ("Rank these Australian birds and animals by how much you like them … Koala, Kangaroo, Wombat, Cassowary, Tasmanian Devil, Kookaburra"). This process provided students with approximately 85 data values for each question to analyse to compare the two cities and the students' activities.

The data from the survey questions were distributed to students working in groups of three and students negotiated the choice of which questions to analyse. Although individual students may have chosen different questions to analyse, discussion was encouraged among members of the group. Students were first asked to produce a representation of their data and to answer questions about the process undertaken by writing in their workbooks. Finally, the students presented their results to the class and there was general discussion about what they had learned about differences and similarities between the two cities and groups of students.

Data Analyses

For the purposes of this paper, the data collection instruments were the student representations and their responses to four questions in their workbooks (Table 1). These tasks were intended to monitor understanding of the three major steps in the practice of statistics (Franklin et al, 2007) related to the activity. Posing and refining questions, which was reported in detail in English et al. (2017), was reviewed in Q4 in terms of what students had learned on this aspect. The representation drawn and Q2 reflected the Analysis undertaken, including consideration of variation, with Q1 and Q3 covering the Interpretation of results and the confidence in the decision made. To analyse the data, rubrics were devised by the authors for the representations and the four questions, as shown in Table 1. Generally, the descriptors for each level, as they incremented, reflected the increasing amount of evidence drawn from the data in the context of the question. Not all students answered every question in the workbook, hence the sample size varies for the questions. Coding was carried out by the third author and an experienced research assistant, with discrepancies in coding resolved by discussion. The level of initial agreement on the coding was 74%. Scores for the representations and Q1, Q2, and Q3 in the workbook were summed for students who completed all three questions, to give an indication of the range of capacity to engage in the Analysis and Interpretation steps of the practice of statistics. The two codes for Q4 were combined for students who gave at least one response, monitoring reflection on writing and refining questions in the light of the purpose for the data collection.

Table 1
Rubrics for analysing student representations and responses to their chosen survey question

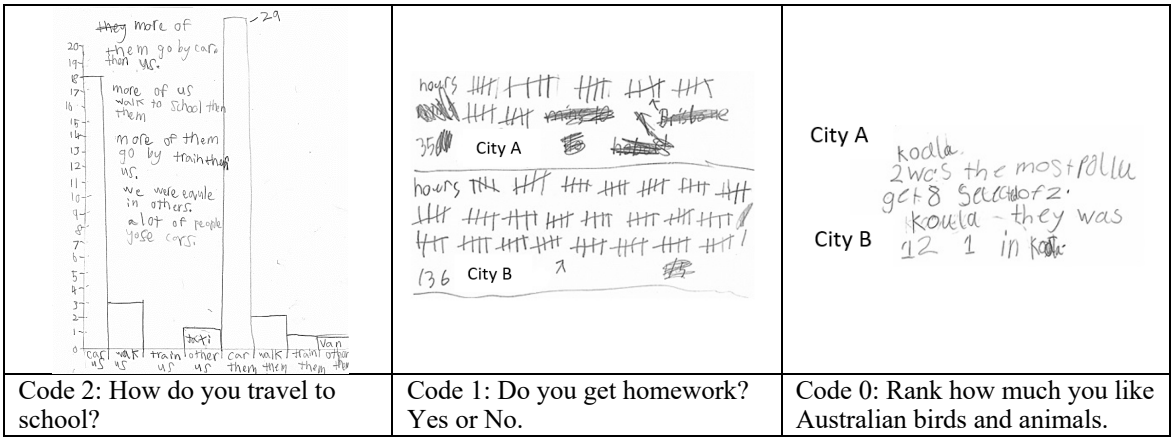
	Code	Description
Representation drawn from the data for chosen survey question	2	Conventional graph type/table appropriately summarising the data
	1	Informal representation adequately summarising the data
	0	Insufficient organisation or incomplete data
Question	Code	Description
Q1. What do the data and your representation tell you about life in City A compared to life in City B? What conclusions have you reached?	2	Justified reason showing recognition of similarities or differences
	1	Statement that they are similar/different without giving a reason
	0	Response does not summarise the data to form a conclusion; Idiosyncratic response
Q2. Were all the data the same? Describe any variation you found.	2	Appropriate description of variation
	1	General statement without description of variation
	0	Idiosyncratic response
Q3. How certain are you that your data and conclusion are true for all Grade 4 students in City A and City B?	3	Recognition that the survey is a sample of the population and hence uncertainty (explicitly or implicitly stated)
	2	Recognition that the survey may not have been answered correctly/truthfully, leading to uncertainty
	1	General statement of uncertainty without reason, OR statement of certainty with valid reason (e.g., because they used/checked the data carefully)
	0	Certainty without a valid reason; Idiosyncratic response
Q4. From doing this activity, what are two things you have learned	2	The type of question/way it is worded is important; OR different types of survey question lead to different data/output; OR response focuses on data collection/analysis, OR consistency/variation.

about writing survey questions? [NB: Each response was coded separately.]	1	General statement about ease or difficulty of writing survey questions; OR response relates to specific survey item/s, rather than surveying in general; OR statement of need to check carefully.
	0	Survey writing is "fun"; Idiosyncratic response

Results

The overall activity was designed to develop students' skills in the practice of statistics: (i) posing and refining statistical questions in developing a survey to learn more about their peers in each city (specifically, to compare their respective city lives), (ii) collecting data by answering questions on-line, (iii) analysing the data by making representations, identifying variation, and looking for trends in the data, and (iv) drawing conclusions and inferences while acknowledging uncertainty. Data about posing and refining questions from step (i), and the collecting data component of step (ii) are reported in English et al. (2017). This paper extends those results by reporting on the students' reflections on what they had learnt from writing survey questions. The remainder of the results are related to the Analyse Data and Interpret Results steps of the practice of statistics. The data presented here are the outcomes for the students from one of the cities (City A).

Data representations. Fifty-three students completed at least one representation of the data for the questions given to their group. Coding was based on the most complete representation presented (see examples in Figure 1). Overall, 43% of the representations were recorded tallies, whereas 32% were bar/value graphs, and 14% were some form of data summary list. Others were considered idiosyncratic. Sixty-four percent of the representations were assigned Code 2, 23% Code 1, and 13% Code 0. Although perhaps informal, it was encouraging to find that 87% of students realised the importance of displaying all of the data.



Code 2: How do you travel to school?	Code 1: Do you get homework? Yes or No.	Code 0: Rank how much you like Australian birds and animals.

Figure 1. Examples of representations created for questions chosen.

Workbook responses. Examples of responses and percentages for the other questions at different code levels are given in Table 2. As seen in Table 2, not all students completed every question in the workbook. Thirteen students left between one and three questions blank but only two of these students scored zero on the workbook part of the activity; both, however, contributed to the subsequent class discussions. The distribution of total scores for the representation, Q1, Q2, and Q3, for the 39 students who answered every question is shown in Figure 2. Seventy-seven percent of students who completed the representation and the 3 questions, received more than half marks, indicating that they provided complete responses for at least 2 tasks. The results for Q4, reflecting on what students had learned

about writing survey questions, show this meta-thinking was difficult at this age. For the 52 students who suggested at least one thing they had learned about writing survey questions, the modal score was 2, with a mean and median of 1.5, out of 4 possible points.

Table 2
Examples of student responses to questions about the analysis of the survey question chosen

Question	Code	Examples
Q1. What do the data and your representation tell you about life in City A compared to life in City B? What conclusions have you reached? (*n*=46)	2 (76%)	[City A] is more sporty in winter which is weird because winter there is hot winter here is cold. [ID143] Most people in [City B] like flowers. Most people in [City A] like trees. [ID110] The houses in [City A] and [City B] are quite different. Bricks are pretty much the only similarity. There is a lot more wood and concrete houses in [City B] than [City A]. [ID127]
	1 (13%)	Most people get no pocket money. [ID125] That [City A] and [City B] like different subjects [ID134]
	0 (11%)	In [City A] it is cold and rains a lot [ID131] For me it would be about an hour and 45 mins. but they do it for couple of hours. [ID111]
Q2. Were all the data the same? Describe any variation you found. (*n*=43)	2 (63%)	No! One of them goes by train and none of us. Lots more of them drive to school than us. One more of us walk to school than them. [ID101] No not all data was the same. They love the gardens and plants. But we don't love gardens and plants. There is one thing that is similar we both love sports. [ID123] The most popular subject [in City A] is maths and in [City B] it is art. The second most popular in [City A] is art and in [City B] it is maths. [ID116]
	1 (21%)	No! Because maybe other people like different things. [ID102] No the data was not the same. [ID110] No, because there were more differences than similarities. [ID158]
	0 (16%)	Both school. [ID117] We both like animals and we both like facts about them. [ID128]
Q3. How certain are you that your data and conclusion are true for all Grade 4 students in City A and City B? (*n*=40)	3 (30%)	It might not be true because some people didn't do it. [ID104] I wouldn't be certain because we don't know anything about the other schools. [ID152]
	2 (18%)	Not very certain because people might have lied. [ID104] 80% because some people could have not been correct. [ID124]
	1 (30%)	Not very certain. [ID102] I checked the chart. [ID111]
	0 (22%)	I am sure that my data is true. [ID118] Yes lots of people thought about the beach all the time. [ID146] Koala will get 1st. [ID105]
Q4. From doing this activity, what are two things you have learned about writing survey questions? [NB: Each response is coded separately.] (*n*=52, 50)	2 (15%) (10%)	You need to ask questions that will give you useful data from the people who you are asking the question to. [ID122] You want a question that will get a variety of answers. [ID113]
	1 (58%) (44%)	That they aren't as easy as you think and you have to check your tallies and make sure of them. [ID142] It was easy to write about survey. [ID115]
	0 (27%) (46%)	It can be really fun. [ID105] The things I learnt about this lesson was all about working out and for me it was all about working the different things you could learn. [ID155] It is difficult. [ID108]

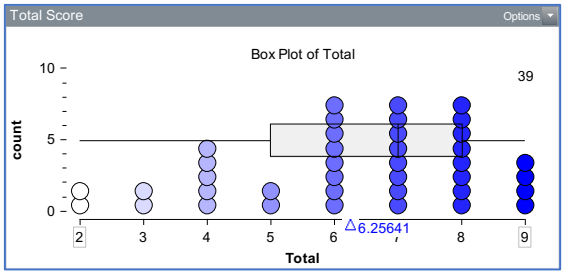


Figure 2. Total scores for the Analysis and Interpretation steps (Representation, Q1, Q2, and Q3).

Discussion and Conclusion

The objective of the activity designed to compare the lives of students in two cities, reported in English et al. (2017) and here, was to create an opportunity for the students to experience becoming statisticians, including the aim of posing their own questions rather than exploring those set by others. It provided the opportunity for the students to engage with their fellow students in the practice of statistics, as envisaged by *GAISE* (Franklin et al., 2007). Specifically, in terms of *The Practice of Statistics: Posing Questions*, the majority of responses considered variation and the actual data that would be produced. For the last question (Q4), thinking back about the process of writing questions, most students focused on the challenge or otherwise of posing their questions. The broad range of responses shows that many students did not reflect beyond their personal experience. The more sophisticated responses, however, related to the appropriateness of questions to generate the data expected. This illustrates the potential for Year 4 students to develop key understandings about posing questions that are foundational to designing statistical investigations (English et al., 2017).

In terms of two steps of *The Practice of Statistics: Analysing and Interpreting Data*, the students were successful in creating representations and describing the variation they saw when comparing life in the two cities. The dominance of tallies used to represent the data suggests that the students were confident in using this graph type. The use of more sophisticated graphical representations by some students, however, suggests Year 4 students have the capacity to build a broader repertoire of graphical representations. In relation to the judgment of certainty, the responses were divided between commenting on not surveying the full population and questioning the reliability of the data. For many students, trusting the data and knowing that they could represent a larger group posed problems. As Watson (2006) suggests, recognising the relationship between a sample and a population is sophisticated.

This activity contributed to building the foundation for being aware of data in the world and creating curiosity about the messages they contain. Hopefully this will be followed by students asking more critical questions when undertaking statistical investigations in the future. The overall aim to create a statistically literate society is a very long process, but it is through students experiencing the practice of statistics and sharing findings with their classmates, that students will develop the ability to participate in society as statistically literate citizens (Gal, 2002; Watson, 2006). A few may actually become statisticians!

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