DEVELOPING PRIMARY STUDENTS' ABILITY TO POSE QUESTIONS IN STATISTICAL INVESTIGATIONS

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How do children develop their own questions to investigate in statistics? Often in school, teachers just give children questions to respond to, but rarely ask them to generate a question that they want to investigate. To write their own statistical questions, students need to envisage the processes and purpose of a statistical investigation. Curriculum documents in many countries have begun to recognise the benefits and importance of children developing their own questions, however little is known about children's development in this area. This exploratory study aims to understand ways that 9 year old children can more confidently construct relevant and reasonable questions that can be answered with a statistical investigation. Results suggest that by using frameworks and peer negotiation to guide their experiences, students improve their ability to write purposeful investigative questions with richer statistical intent.

INTRODUCTION

An effective investigative question provides students with an ideal entry point into the statistical inquiry cycle and a focus for the critical thinking and inferential reasoning needed to reach the inquiry conclusion (Arnold, 2008; 2009; Chin & Osbourne, 2008). Research acknowledges, however, that writing good statistical questions is problematic for students (Pfannkuch & Horring, 2005; Burgess, 2007), but gives little direction in terms of how students can be taught this important skill. This paper reports on an exploratory study in Australia aimed at understanding processes of students' learning to write questions that can be answered with a statistical investigation. We explore how an inquiry classroom using questioning frameworks and student negotiation can improve students' ability to write purposeful investigative questions with richer statistical intent.

LITERATURE AND FRAMEWORK

According to Chin and Kayalvizhi (2002) and Arnold (2009), a good investigative question requires students to: Generate and collect data for a selected pathway; represent, analyse and interpret their findings using the data collected; draw a conclusion using their results; and justify their findings to the question based on the data they have collected. Chin and Kayalvizhi (2002) further suggests that in order to fully engage students and sustain their interest, these questions should be conceptually challenging, meaningful and relevant to their personal experiences whilst remaining broad enough to enable critical and creative thinking.

Formulating investigative questions is a skill that needs to be explicitly taught (Walsh & Sattes, 2005). As they begin the process of formulating their own questions, children are likely to generate questions that resemble traditional word problems (Lowrie, 2002). By modelling well constructed questions (correct syntax and semantics) and demonstrating how variations in the wording can alter the data that is collected, teachers can assist students to produce more workable investigative questions (Chin & Kayalvizhi, 2002). However, Arnold (2008) recognises that just modelling investigative questions is insufficient to change students' ability to pose effective questions—they also require an understanding of what an investigative question is. Additionally, the literature suggests a number of elements to consider in supporting students to write investigative questions:

- The importance of having students consider the aggregate view of data rather than the individual view when formulating statistical questions (Arnold, 2008);
- Ensuring that students have sufficient interest, knowledge or experience in a topic to pose meaningful questions (Chin & Kayalvizhi, 2002; Pfannkuch & Wild, 2003);
- The benefit of peer interactions to co-construct contextual understandings (Chin, Brown, & Bruce, 2002) and assist students to clarify and focus their questions (Lowrie, 2002; Chin & Osbourne, 2008).

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METHOD

This study used exploratory action research with research questions:

- *Can children's investigative question posing be improved with experience?*
- *What challenges do children encounter when posing their own statistical questions?*
- *What types of experiences support students' ability to pose questions suitable for statistical investigation?*

The key participants were a class of nine year old children (Class A, n = 25) from a suburban school in Australia who were taught a unit on writing statistical investigation questions. Initially, students were asked to write mathematical investigative questions for one of two stimuli (provided by the researcher): a can of peaches or a shower timer. Eight weeks later, students repeated the task using the alternate stimulus. Two other classes in the same school were given the same tasks as a point of comparison: Class B (n = 19) had also been conducting statistical investigations (but not focused on student-generated questions) while Class C (n = 22) had not been conducting statistical investigations. Because a larger study had been going on for a number of years in the school (Makar, 2008), there were students in each of the three classes who had experience with conducting statistical investigations from previous years. At the conclusion of the unit, students in the target class (Class A) completed a structured reflection sheet to communicate what they had learnt about formulating investigative questions. Research notes were also kept.

Questioning Unit

Students completed an eight lesson unit on creating investigative questions over the period of one month. During the unit students worked individually, in small groups and as a class to:

- Generate characteristics of investigative questions;
- Sort the initial questions written by the class into investigative and non-investigative questions (providing justifications for their choices) to highlight characteristics of investigative questions;
- Envisage the data that could be used to address an investigative question;
- Collaboratively refine descriptive questions to more inferential ones through the use of ambiguous words (e.g., 'best') to compare, identify preference, evaluate or predict.
- Consider the purpose and potential interest in the solution to their question.

Analysis

Drawing on the literature, particularly work by Chin and Kayalvizhi (2002) and Arnold (2009), a hierarchy was created to scaffold and assess students' statistical investigation questions.

- *Irrelevant/Off topic:* no clear connection to the stimulus;
- *Non mathematical:* does not require mathematics to reach a solution;
- *Non investigative:* are impractical to investigate (in terms of classroom constraints), can be answered simply by checking a reference or have no real purpose or interest for others;
- *Closed:* have a definite answer that can be worked out using information directly available;
- *Potential for investigation:* capable of refinement into investigative questions;
- *Investigative:* met characteristics of investigative questions (e.g., Chin & Kayalvizhi, 2002); and
- *Inquiry:* investigative questions containing ambiguities that needed to be negotiated.

The 197 student-generated questions were sorted qualitatively into these categories and ranked on a continuum from 1 to 7 (Table 1). A random selection of questions (25%) was ranked by a second researcher resulting in 85% agreement; differences were negotiated and agreed upon.

FINDINGS

The means and standard deviations of each student's 'best' initial question (before the teaching unit) were quite similar across the three classes (Table 2, $F = 1.47$, $p = 0.24$). These results

suggest that initially, students across all three classes were typically able to write a question that was mathematical and relevant to the stimulus, but non-investigative or closed in nature.

Table 1. Examples of student-generated questions at each level from can of peaches stimulus

Level	Question category	Example (from student data)
0	No attempt	-
1	Off-topic/irrelevant	How many litres are there in five 350ml glasses?
2	Non-mathematical	How do peaches grow?
3	Not investigable	How many peaches does an average peach tree grow in a year without any growth food?
4	Closed	How much fat, sugar and salt are in a can of peaches?
5	Potentially investigable	What size are the peaches inside [a can]?
6	Investigable	Is there the same amount of peaches in every tin?
7	Inquiry	What peach manufacturer sells the healthiest tinned peaches?

Table 2. Initial attempts at writing investigative questions

Class	n	Stimulus	Mean (sd) of best response	Proportion writing good question (rated 6-7)
A: Inquiry class (with questioning unit)	25	Canned peaches	3.9 (1.4)	4%
B: Inquiry class (without questioning unit)	19	Shower Timer	3.6 (1.4)	11%
C: Non-inquiry class	22	Canned peaches	3.1 (1.4)	9%
Overall	66		3.6 (1.4)	8%

As all three classes contained some students who had long-term experiences with inquiry-based learning from previous years, the initial results of students with and without substantial inquiry experience were also compared. The results revealed significantly higher initial levels of questions (Figure 1, $t = 3.81$, $p < 0.01$) from students who had 1-2 years of inquiry experience ($n = 19$), regardless of the class they were in. This suggests that experience with inquiry provides some level of expertise with students' ability to write investigative questions.

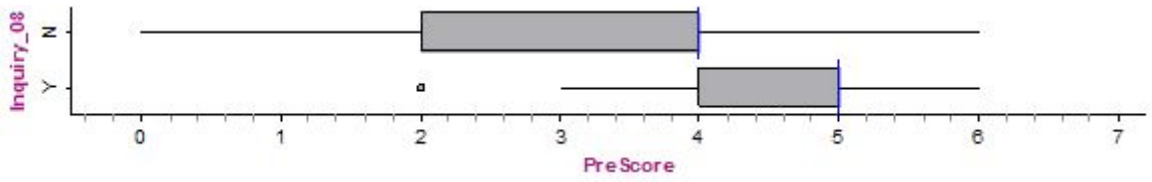

Figure 1. Level of initial questions across students with recent extended experience with inquiry

Over the course of the four-week unit, students faced a number of challenges in their work as well as some experiences at key junctures that helped them to deepen their understanding of the process of statistical investigations, statistical concepts needed to conduct an investigation, or extend their understanding of the context of their investigation. We describe these challenges and opportunities below.

Challenges and Supports for Learning

Connecting question to purpose. Over the course of the unit, several aspects of writing investigative questions emerged as challenging for students. The difficulty in seeing questions that were statistical (i.e., could be answered with data, as suggested by Arnold, 2009) was one area that students struggled with initially. However as students began to list questions that they thought would be statistical, they realised that many of these questions lacked purpose. Questions like "How many peaches are in a can" or "What size are the peaches in a tin?", prompted students to debate whether these questions would be useful to investigate.

This concern about purpose brought students to consider the utility of ambiguous words as a way for the investigator to define the question according to their purpose and the data they could collect. The opportunity that ambiguous words provided students in writing inquiry questions resurfaced several times during the unit. In their final reflection, 57% of students listed ambiguous words as a concept they found helpful in understanding how to write an inquiry-based question:

> *Using ambiguous words can give you more pathways to explore.*
> *I try to make it [an investigative question] general, so there is more to investigate. If I make it too specific, the amount of things we can investigate gets smaller and smaller.*

Interestingly, ambiguity is often considered contrary to writing good statistical questions. Although one needs to clarify and define ambiguities in a question before one can investigate it, students began to recognise that the breadth from ambiguity can make it easier for students to connect the question to an investigation of interest. This required, however, that students be able to envision the inquiry process in order to understand how to connect their question to the data and the conclusion drawn (Fielding-Wells, 2010). That is, the understanding of the investigative process that follows question generation was important; otherwise the ambiguity caused students concern as it did not give them enough clarity to continue their investigation.

Syntax and meaning. The syntax of an investigative question was also challenging for students. One element of this was the importance of writing a question that would move beyond the 'oneness' of a topic towards a question that allowed for inferential reasoning. For example, "How many peaches are in *the* can?" (specific) is subtly different than "How many peaches are in *a* can?" (general). The more general version allows for one to collect data on several cans and try using the data to infer the number of peaches in a (typical) can. Syntax was also an issue in writing questions that were logically constructed and able to communicate their meaning. *How much water does all of Australia use with the 4 minute shower timer?* Or, *Do people prefer slow 4-minute timers or fast 4-minute timers?* In both of these examples, the meaning of the question is sometimes limited by children's ability to express it. This was a drawback of working with younger children on such a challenging topic as they are still developing their language and literacy skills.

Negotiation. Students were presented with several opportunities to pose questions individually, with a partner, in a small group and as a class. Students often struggled and were less willing to commit pencil to paper when asked to pose these questions individually. Working with a partner or small group, students engaged in substantive conversations about what constituted a good investigative question and often negotiated both its content and wording several times (generally resulting in better questions). This theme came out clearly in their reflections:

> *It helps me think and everyone's got an idea and everyone's involved.*
> *Everyone throws in ideas and if you don't understand one of the group members can help you understand.*
> *With a partner or a group you can tell them your idea and they can tell you how to improve it.*
> *If I do my work first, then brainstorm it as a class, I get more ideas to go back and improve my question to make it a higher standard.*

Seeing the mathematics. The initial question posing by students indicated a deficit in students' understanding of the role mathematics plays in identifying and posing a good investigative question. Broadening students' understanding that an investigative question requires them to generate, collect, represent and analyse data provides a useful scaffold for them to identify the mathematics they would encounter as part of the investigation.

> *I know I have to always collect data if I want a good question and compare it by putting it on a graph, table, tallies etc*
> *Seeing the maths to me is just like planning a story; it leads me through the process. It is like a stimulus to me as it helps me with the choice of wording I use.*

Context. Context played a significant role in the students' ability to pose effective questions. Without a workable knowledge of the stimulus or a purpose for their question students

found it difficult to engage with a topic. The students were more readily engaged with the process of question processing if the stimulus interested them.

Final analysis

Several weeks after the end of the unit, students in all three classes were again given a stimulus and asked to write a question that could be investigated. The target class showed a higher quality of question type compared to the other classes (Table 3, $F = 10.1$, $p < 0.01$), with no significant differences between the other two classes. So while there appeared to be differences initially in students with previous experience in inquiry, the focus on developing students' question writing skills appeared to further support their ability to do so.

Table 3. Students' final attempt at writing an investigative question

Class	n	Stimulus	Mean (sd) best response	Proportion writing good question (rated 6-7)	Change mean (sd)
A: Inquiry class (with questioning unit)	25	Shower timer	5.2 (1.6)	60%	1.4 (1.2)
B: Inquiry class (without questioning unit)	19	Canned peaches	3.5 (1.5)	11%	-0.1 (2.1)
C: Non-inquiry classroom	22	Shower timer	3.6 (1.3)	0%	0.5 (1.4)

Student reflections highlighted the confidence they gained from focusing on writing investigative questions (100% rated themselves as having improved) and reiterated the elements that they found particularly useful for their learning.

> *A good investigative question would cause discussion and people would have to collect data, organise or represent it and then interpret it. A good investigative question contains airy fairy words to make them more open.*

DISCUSSION

The purpose of this exploratory study was twofold: (1) to investigate whether explicitly targeting students' question-writing skills can help them gain proficiency and confidence in writing questions appropriate for statistical investigations, even at a young age; and (2) to highlight the challenges and potential supporting elements that students encountered in learning to write investigative questions. Students initially found it quite challenging to write questions appropriate for a statistical investigation. In particular, they found it difficult to focus on investigative questions that were feasible and had accessible data, took account of an interesting purpose within the context, and got beyond the 'oneness' of the particular stimulus in front of them. Through the course of learning to write investigative questions, students' noted the utility of the ambiguous words to assist them in thinking more generally (inferentially) about the phenomenon under investigation. That is, it wasn't *that* tin of peaches that they were interested in investigating but the general characteristics of tinned peaches that should serve as the focus of their question. The opportunity to consider different structural contexts of investigations (e.g., comparisons, preferences, evaluation, prediction) was also a supporting element students noted. Finally, the social interactions with their peers had several benefits for both generating and improving their question-writing skills. These negotiations opened up new ideas, helped them to think more critically and purposefully about their investigative questions, and allowed them to refine the wording of the questions for improved clarity and meaning.

The data also reveal that it wasn't the inquiry-based learning environment alone that enabled students to improve their ability to write good investigative questions, but the focus on questioning skills within that inquiry-based environment. Furthermore, the importance of students' contextual knowledge and interest in the phenomenon to be investigated contributed to the depth and meaningfulness of the questions students were able to write.

While exploratory in nature, this research provides an impetus to consider the benefits of targeting questioning skills to deepen students' statistical literacy and reasoning within the statistics

curriculum. By being more explicit in supporting students' understanding of the aspects of an investigative cycle that precede data analysis, there is potential to improve students' understanding of the earlier phases of the statistical investigation. As emphasised by Shaughnessy (2007, p. 963):

> Most of the current statistics education in the United States places a heavy emphasis on the DAC parts of the [PPDAC] Investigative cycle, but precious little time is devoted in classrooms to the PP parts. If students are given only prepackaged statistics problems, in which the tough decisions of problem formulation, design and data production have already been made for them, they will encounter an impoverished, three-phase investigative cycle and will be ill-equipped to deal with statistics problems in their early formation stages.

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