TOWARDS POSING AND ANSWERING QUESTIONS ABOUT BAR GRAPHS

Malia S Puloka and Maxine Pfannkuch
Waipapa Taumata Rau | University of Auckland, New Zealand
m.puloka@auckland.ac.nz

Posing questions about categorical variables and answering them using representations is a neglected area of research. A small exploratory study was conducted with 13-14-year-old Pasifika and Māori students using culturally appropriate data and pedagogy. Data collection included pre and post-tests and a video-record of a 10-lesson implementation. The findings indicated novice students could learn to pose quantitative questions about categorical variables but struggled to deconstruct questions and to decode representations to answer simple, conditional, and joint questions. The implications of the findings are discussed.

INTRODUCTION AND LITERATURE REVIEW

Bar graphs are ubiquitous, but little is known about the teaching and learning of posing simple, joint, and conditional questions and choosing and interpreting bar graph representations to answer the questions (Budgett et al., 2022; Xiong et al., 2022). Even though bar graphs are part of the junior curriculum, the development of knowledge and facility with reasoning from and interpreting multivariable bar graphs is a neglected area of research and practice. Within a data-centric world, posing and answering a myriad of different types of questions involving categorical data and bar graphs is essential. The purpose of this paper is to explore novice student attempts at engaging with posing questions about two categorical variables, leading towards answering questions with one and two-variable bar graphs, using personally relevant data to them, which was part of a larger project.

Recent publications (e.g., Bargagliotti et al., 2020) have highlighted the need to develop students' ability to pose questions when dealing with data. Arnold and Franklin (2021) identified four different types of questions necessary for statistical investigations – statistical investigative questions, survey or data collection questions, interrogative questions, and analysis questions. Interrogative questions are used at every stage of the statistical investigation cycle, statistical investigative questions in the problem stage, survey or data collection questions in the plan stage and analysis questions in response to representations in the analysis stage. According to Gould et al. (2017), students' ability to pose suitable investigative questions is crucial in facilitating their capability to explore and unlock the stories in the data. Much of the attention, however, has focused on posing questions with two numerical variables and one numerical versus one categorical variable, not two categorical variables (Arnold, 2013; Arnold & Franklin, 2021). My research on Grade 12 students (Puloka, 2016) and undergraduate students (Budgett & Puloka, 2019) found they had difficulty posing questions about categorical data. Furthermore, after posing a question students struggled to identify a representation when using an eikosogram or bar graphs that could answer their question. Despite the plethora of research related to categorical data (e.g., Böcherer-Linder et al., 2018), the focus of the research has typically been on student responses to tasks that give one representation and several questions. A prevalent finding from research is that students find it difficult to interpret the language used in the questions and to decide, for example, whether the question is about a joint or conditional situation and if it was conditional to decide the conditioning variable (Batanero & Álvarez-Arroyo, 2024).

Although frequency-based information and visualisations have been shown to improve performance in interpretation of chance-based information, the previous studies did not require participants to select an appropriate representation or to articulate its interpretation (Budgett et al., 2022). When reasoning with one-variable frequency bar graphs, students often interpret what they see on the display and may not reference the total or sample size naturally (Konold et al. 1997; Puloka, 2016). Two-variable side-by-side frequency bar graphs produced similar findings in that students often compared frequencies between the grouped data rather than the proportions, which require identifying and calculating the correct frequency totals from the graphs (Watson & Callingham, 2015). Similarly, Casey et al. (2018) reported that the middle school students in their study found it difficult to interpret side-by-side bar graphs and they "struggled to know what to compare and often compared frequencies rather than relative frequencies" (p. 5). Moreover, when answering questions from these graphs it is

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necessary for students not only to unpack the language of the question, but also to decode the graphs, for example, the conditioning variable, before comparing proportions.

In statistics education, it is considered that novice students need to deal with data-based situations that are engaging and personally relevant to them (Ben-Zvi et al., 2018). Also, students need to have contextual knowledge about the data since statistical thinking requires an integration of statistical and contextual knowledge (Wild & Pfannkuch, 2019). When interpreting data there is a constant shuttling between the statistical and the contextual spheres and furthermore the rationale for statistical investigation is learning more in the context sphere (Wild & Pfannkuch, 1999). From a marginalisation of minority groups perspective, Hunter and Hunter (2017) argued that the context of a problem is an important consideration for enabling Pasifika students to recognise that their cultural activities are valued and to give them confidence in their mathematical capability. Cultural ideas related to probabilistic thinking should also be considered (Morris, 2021). Thus, the context of problems should be connected to the students' world, culture, and social contexts.

There is limited research on posing questions for two categorical variables, selecting appropriate bar graphs to answer the questions, and answering questions using bar graphs. Considering that bar graphs are ubiquitous on information dashboards and encourage viewers to make comparisons and draw conclusions, it is crucial for statistics education to attend to improving students' capability in asking questions and interpreting multivariate categorical data using diverse representations and situations (Budgett et al., 2022). The research questions are: Using a culturally appropriate context, what are the challenges for novice students in (1) posing questions when given two categorical variables and (2) answering questions using physical demonstrations, two-way tables, and bar graphs?

METHOD

The larger project involved the design and implementation of a 10-lesson unit of work, created using a design-based research perspective, followed by a retrospective analysis with the aim of developing a local instruction theory. The implementation was based on Pasifika values of Alofa (Love, Dignity, Respect) and Fonua (Belonging, Connectedness) and approaches, where knowledge is co-constructed with participants in a family-oriented classroom in a culturally appropriate setting (Ministry of Education, 2020). For example, the value of being respectful to elders can be a barrier in the classroom in terms of students asking and responding to questions (Hunter, 2023). As a Pasifika elder I, the first author, can allow the students to talanoa (Vaioleti, 2006) or korero with me, thereby extending their boundary but at the same time maintaining respect for each other and thus students can feel more confident to step out further comfortably. A talanoa is a discussion underpinned by Pasifika cultural norms and practices for engagement and interactions with others. A korero is the Māori equivalent. This small exploratory study was conducted with 13-14-year-old Pasifika and Māori students in a mixed ability class in a low socio-economic school. Eleven students consented to participate in the study. Data collected were pre- and post-tests, given before and after the implementation of the teaching unit, student and teacher artefacts, and videos recordings of the implementation.

BACKROUND TO TASKS

The pre-test revealed the students were not familiar with reading and interpreting datasets and only 20% of the questions posed by the students were quantitative (Puloka et al., 2021). Moreover, students were unable to answer questions about two categorical variables presented in two-way tables and bar graphs. The first three lessons in the teaching intervention centered on constructing variables, designing survey questions for collecting data from the class, and reading and interpreting the resultant NAME dataset (Figure 1) and data cards.

name	gender	ethnicity	age	s_letter	numletters	vowels	length	middlenam	namesake	origin	namefrom	unisex	born	who_side
	male	Maori	13	cons	4	2	short	2	yes	father	English	don't know	NZ	father
	male	Samoan	14	cons	5	1	short	1	yes	mother	Samoan	yes	NZ	mother
	male	Fijian	14	cons	5	2	short	2	yes	mother	Fijian	no	NZ	mother

Figure 1. Part of the NAME dataset with student names removed for confidentiality reasons

When considering the context for constructing variables, I chose to use student names, as great importance is attached to naming a child in Pasifika communities and thus, I could integrate and weave the students' learning into their culture and interests. Hence, the data used by the students were

connected to cultural or Pasifika knowledge about names and were personally relevant to them. Students learned in these initial lessons how one could construct variables and data from their names, and that from the class dataset they could learn new information about each other (Puloka & Pfannkuch, 2023).

RESULTS

The results are presented in two sections to enable the reader to follow separately the evolution and challenges of question posing for students across six of the lessons and their responses to answering them, even though they occurred within the same lessons. The results for each section are drawn from the video recordings of the implementation of the lessons. Salient episodes from the lessons were chosen to illustrate the challenges students were having during learning. Lastly, each section refers to some results from the post-test to highlight the difficulties students were still facing.

Posing questions

Posing questions from the NAME dataset occurred at the end of Lesson 3. Based on my knowledge of Pasifika and Māori cultures that sons, especially the eldest, are named by their father or father's side of the family, I stated I had noticed that most of the boys were named by their father or father's side of the family and that my investigative question would be, "Out of all the boys, what proportion was named by their father or father's side of the family?" Students immediately started to call out the answers such as "*eight*", "*majorities*", "*six*". The most prevalent questions were one-variable frequency-based questions such as "*How many people have short names?*", "*How many people were born in their country of [ethnic] origin?*". Some questions were about one datum, "*Is it [a particular name] a namesake name?*", or were curiosity questions, "*How do students know that they were named after their father's side?*", "*What is the translation [of the names] to English?*". To encourage students to pose questions about two variables, I picked two, for example, Ethnicity and Unisex, to which one student responded, "*How many Cook Island Māori was unisex?*", which we revised collectively to, "Out of the Cook Island Māori students how many have unisex names?". After each question was asked, students automatically called out potential answers that were either qualitative (e.g., lots) or quantitative whole numbers (e.g., 2), not fractions.

By Lesson 6, when students were given the two variables Gender and Namesake and asked to pose three questions, they posed mainly simple and conditional questions with very few being frequency-based. However, they needed assistance with the wording of the questions, for example, "*What fraction are boys?*", which, in a class discussion, we co-constructed into, "What fraction of the class are boys?". For joint questions, I needed to give an example, emphasizing key words (e.g., the class, and) for the question "What proportion of the class are male and have namesakes?", from which they could develop their own questions. The students were then given a worksheet, part of which asked them to pose questions about the variables Namesake (Y/N) and Length of name (Long/Short) and to identify the type of question, that is, simple, conditional, or joint. Once they had finished each student wrote one of their questions on the whiteboard under the type of question. There were noticeable improvements with regard to the structuring of the questions and language use. For example: "*What proportion of the class have a namesake?*", "*Of all those with namesakes, what proportion have long names?*", "*What proportion of the class have namesakes with a short name?*". There were incomplete sentences such as "*Fraction who have long namesake*" but the main idea was present. There was still confusion about the language to use for each type of question, for example, "*Of all those with namesake what fraction of class have short name?*".

Lesson 8 started with bar graphs (Figure 2) we had co-constructed in Lesson 7, after physically enacting them with human bar graphs. In Figure 2, a long name was defined by students as one with eight or more letters and the variable Origin was defined as "whose side of the family gave the student their name", where the response could be "Mother, Father, Other". The students were then asked to pose questions about the bar graphs in their groups, but the students indicated their preference for a class discussion, resulting in students contributing questions with some of the questions being co-constructed with me. The first question posed was "*What fraction of short names is named by their mother?*" followed by many simple questions such as "*What proportion of the students are named by their father's side?*" To encourage students to articulate a conditional question, I asked the students to finish off a question that began with the word "Among". Immediately a few students responded and eventually formed the question, "*Among those who have long names, what fraction is named by their father's*

side?" I then requested a joint question. One student wondered whether a joint question was one where there are multiple answers. Another student responded, "*Where you combine two questions together with the 'and'.*" Then he said, "*What proportion was named by their father's side and have long names?*"

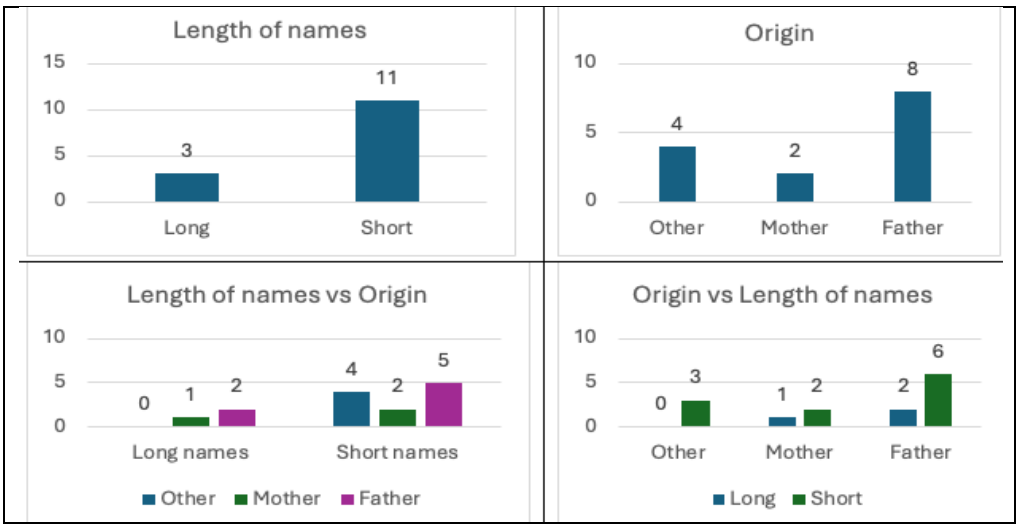

Figure 2. Four bar graphs generated for the variables Origin and Length of Name

Based on the class discussion that took place in Lesson 8, it seemed overall the students' question-posing skills had improved as it did not take that much time for them to come up with questions compared to previous lessons. As well as being familiar with the structure of different types of questions, some of the students could also verbally identify and justify different types of questions. For example, they could point out the variable that made the question conditional and how the question applied only to that variable group and point out that joint questions were the ones where the word 'and' is used. Simple questions were posed more frequently than the other types of questions. None of the questions posed were about frequency or began with "How many", which was considered an improvement in students' question posing skills. Finally, given a worksheet at the end of Lesson 8 with four similar graphs to those in Figure 2 using the variables Gender and Namesake, 44% of the student questions were simple, 33% conditional and 22% joint and none were frequency-based. In the post-test, given a set of four graphs, 54% of the questions posed were simple, 14% joint, and 14% conditional with about two-thirds of them being frequency-based; 18% were curiosity questions. When compared to the pre-test, where 20% of the overall questions students posed were quantitative, the post-test showed that more than 80% of the questions for the bar graphs were quantitative, although predominantly frequency based.

Answering questions

Lesson 4 started with an activity to show why proportion answers to questions were necessary. I then took the questions posed in Lesson 3, and in a whole class-discussion co-constructed some of them into fraction or proportioned-based questions, and classified questions into simple, conditional, joint, comparison, those not about a group of interest, and those that could not be answered with the data. To answer the questions, I decided not to use the NAME dataset, and rather use information from the students present in the class to be able to enact the responses through physical demonstrations. The first student-posed question was a simple question, "*What fraction of the class are boys?*" To answer the question, I asked the class to put up their hand if they were a boy. One of the students counted the number loudly. When asked what the answer was, some of the students responded, "*ten, 75.*" The response "75" was interpreted as referring to an approximated percentage of the students who were boys. I then asked for a fraction with more than one student calling out "*ten out of twelve*." On asking for clarification, they answered that there were ten boys in the class out of twelve students in total.

To answer the conditional question, "Of all the boys, what proportion was named by their father's side?" some of the students' responses were, "*tally it, tally chart, count their names from the*

data, putting up hands." After asking students to put their hand up if they were a boy named by their father's side, a student counted seven. When deciding the total, the following conversation took place:

R: *So, what should I write down?*
S: *Seven out of twelve.*
R: *Seven out of?*
S: *Twelve.*
R: *Seven out of twelve? ...Should it be --*
S: *Out of ten. S: Seven out of ten.*
R: *...Why...?*
S: *...related to boys. S: Oh yeah! S: Seven out of ten boys.*

In a similar fashion, more questions were answered with students gradually taking the lead through deciding how to answer the question, by putting hands up or standing up, counting the students for the numerator and then resolving the denominator often using my help to unpack the question through my emphasis on particular words such as "what proportion *in the class*" for the question "what proportion in the class are boys and were not born in New Zealand?"

In Lesson 5, the battle to answer questions using proportions and to identify the denominator continued as students shifted to working with two-way tables. For example, I would read out the question, "What proportion of the class have namesakes?", to which they responded "*8*". When I emphasized the word proportion in the question, they immediately said, "*eight out of 11*". For the conditional question, "Of those with namesakes, what proportion were named by their father's side?", they said "*five over 11*". When I asked them to explain why, they demurred, but before I could finish saying the phrase "Of those with namesakes", they called out "*five over eight*". When I asked, "why eight", they responded that it was because eight students had namesakes. For the joint question "What proportion of the class have namesakes and were named by their mother's side?", the students' responses started with "*three, three out of three*" then to "*three out of eight, three out of six, three out of eleven.*" I acknowledged that three is part of the answer and then one of the students called out, "*Oh no, it's three out of eleven. What proportion of the class*" with great emphasis put on the word "class." In summary, students could easily identify the numerator for answering questions. Identifying the denominator during physical demonstrations appeared much easier for the students than paper data displays, because they could physically see the total that needed to be used. To learn how to identify the denominator when using paper data displays, emphasizing key language in each question type seemed to assist these students.

Bar graphs, however, proved much more difficult for students to identify the denominator, because students could not read a number as they could in two-way tables, but had to calculate it. The class were given a set of four graphs, similar to Figure 2, on Gender and Namesake to work on individually in class. While all students could pose the different types of questions about the data for the bar graphs, they struggled to answer them. In the post-test, only five students answered the one simple, two conditional, and one joint question about a set of four bar graphs, where the variables were NZ Born (Y/N) and Number of languages (one, two, > two). To answer a question, the students needed to first select an appropriate graph, then extract the correct numerator, and finally identify and calculate the denominator. The students struggled to identify the appropriate graph, identify and calculate the denominator, identify the correct conditioning variable, and interpret the language in the questions. The following examples show those struggles. For the simple question, "What proportion of the students can hold a conversation about a lot of everyday things in only one language?", two students chose the wrong graph and calculated the proportion of NZ born students who could hold an everyday conversation in one language. For the first conditional question, "Given the students are NZ born, what proportion can hold a conversation about a lot of everyday things in more than two languages?", two students gave the correct proportion for the question, "Given the students can have an everyday conversation in two languages, what proportion are NZ born?" That is, they swapped the conditioning variable and interpreted "more than two" as "two". For the joint question, "How likely are the students to be born in NZ and can hold a conversation about a lot of everyday things in two languages?", two students extracted relevant numerators, but could not identify the denominator, whereas two students interpreted "how likely" as a request for a descriptive response rather than a quantitative response with, "they are not likely because there is not that many that can talk 2 languages" and "likely". This post-test result

illustrates the many difficulties students face when learning to answer questions posed about a set of bar graphs.

CONCLUSION

This study has many limitations, namely the small number of students participating, and inconsistent attendance. The study also was the first iteration of the implementation and hence based on this retrospective analysis of the results; many modifications and improvements need to be made. Nevertheless, some observations as well as reflections on improving practice can be drawn about the challenges these students encountered as they started to learn about posing questions about categorical variables and how to answer them as they moved from physical demonstrations to two-way tables towards bar graphs. With regard to posing questions, the students generally moved from posing one-variable frequency-based questions to one and two-variable proportion-based questions during class time. The representation – database, physical, data cards, two-way, or bar graph – did not seem to be a barrier to posing questions. In learning to identify the three types of questions, simple, conditional, and joint, key words needed to be emphasised, such as the key words for the denominator, the condition, and the word "and" for a joint question. For novices, consideration needs to be given to having the same structure and wording for each question and for the condition to always use the same phrase (e.g., among, out of) and for the denominator to be put in italics to emphasise its importance. For example, "*out of the boys*" indicates that the denominator is going to be the total number of boys and using "out of" consistently in conditional questions would help indicate the group of interest and to build familiarity with the question structure before introducing similar phrases and other language. In a similar way, Arnold (2022) contended that for novices, investigative questions should always use the same wording, so students know what representations to use. Clarifying and identifying the denominator in a chance-based situation is a well-known problem in people's cognition (e.g., Lumley, 2022) and I conjecture it needs to be clearly identified in all three question types for students, similar to identification of the "group of interest" in the investigative questions for two numerical variables and, one numerical and one categorical variable (cf. Arnold, 2022).

In alignment with structuring suitable questions, there was the problem of deconstructing them to answer the questions, reinforcing the need for sufficient time being given to show how they relate to the data, and to limit the language and structure of questions for novices. Initially, students answered questions using only the numerator, but by the end of the implementation they generally were aware of the need to answer with a proportion even if they struggled to identify and/or calculate the denominator. Identifying the denominator using physical demonstrations was easier for the students as they could *see, feel, or embody* the denominator, whereas identifying the denominator in two-way tables required unpacking the question to know where to locate the key word(s) for the denominator. Bar graphs were problematic for these students because of the need to select an appropriate representation and to decode the graphs to answer the questions, a finding that is confirmed by Budgett and Puloka (2019) for undergraduate students and Casey et al. (2018) for middle school students. On reflection, giving four graphs that could be drawn for two categorical variables was too difficult for novices, and future implementations will need to build up from one bar graph to four and from answering simple questions to joint questions.

More research is needed on how to develop student skills and knowledge in this area: in particular, proportional reasoning, decoding, and interpreting bar graphs quantitatively, selecting bar graphs to answer questions, development of and interpretation of language associated with simple, conditional, joint, as well as comparison questions. The language issues could benefit from a partnership with language teachers. Even though students used personally relevant and culturally appropriate data, the focus on posing and answering the three types of questions dominated and therefore student attention was not drawn to how the questions they posed and answered could help them learn more or new information about the context, their names or cultural knowledge, an important aspect of statistical enquiry (Wild & Pfannkuch, 1999). The challenge for future iterations of the implementation is how subsequent lessons could intertwine learning new content knowledge with gaining new insights about names in general, including the rationale for asking questions and reasoning from bar graphs. Cultural knowledge related to data needs to be more than just about the data, rather ways need to be found that integrate discipline knowledge within the learning trajectory that has meaningful outcomes in both the cultural and discipline spheres (cf. Hunter & Hunter, 2017).

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