STATISTICAL LITERACY AND THE ROLE OF COMMUNICATION

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Communication is vital in the practice of statistics, and accordingly, curriculum documents often call for clear and concise communication with respect to statistical content. However, little attention has been given to developing the skills necessary for effectively using written communication to tell the story in a set of data. Too often students bring a mathematical approach to the writing, using statistical summaries without explaining how these connect to the context. Just as students need to learn what is important in communicating with a visual display, they also need guidelines in learning to communicate using words and numbers. This paper addresses the questions: what are characteristics of a good statistical story, and what are strategies to help learners develop skills to communicate the results of a statistical analysis in language accessible to an audience unfamiliar with statistics. The work is based on a research project involving prospective elementary teachers.

INTRODUCTION

A central element of statistical literacy is the ability to communicate statistical information (Gal, 2002). Many curricula documents (e.g., Brazil Ministry of Education; New Zealand Ministry of Education, 2014), recognizing this central role of communication, call for clear and concise visual, written, and verbal communication with respect to statistical information. *Guidelines for Assessment and Instruction in Statistics Education (GAISE) II* (Bargagliotti et al., 2020) states, "…anyone who uses data should ….make decisions with confidence understanding that the art of communication with data is essential", and both GAISE II and the GAISE College Report (2016) explicitly mention the ability to communicate results, including presenting evidence-based claims related to real-world problems. Communication is important both for students who will be consumers of statistical information as it allows them to critically evaluate arguments based on data (Garfield & Gal, 1999), and for those who are producing statistical information for consumption by others such as politicians, journalists, and the general public. Being able to communicate statistical ideas allows students to demonstrate statistical competence (Rumsey, 2002), statistical literacy (Garfield & Gal, 1999) and statistical thinking and reasoning (Woodard et al., 2020). However, while some (e.g., Tufte, 2001; Unwin, 2021) have written about effective communication using visualization, little attention has been given to developing the skills necessary for effectively using written communication to meaningfully describe a set of data.

Much of the existing research focuses on advanced undergraduate or graduate students. For example, Khachatryan and Karst (2017) argue that communication skills should be developed at the same time as critical thinking skills in working with data in support of the learning process, and describe a program to develop these skills in such students. Some papers focus on how statisticians should communicate to clients (e.g., Lowe, 2016), while other papers focus on how to prepare written reports from large-scale projects or analyses of a data science investigation (e.g., Kwok, 2013).

Too often, students in introductory courses bring a mathematical approach to thinking about data, describing the data using statistical summaries without explaining how these connect to the context; making statements and conclusions without using statistical analyses; or presenting all numbers or all words. Just as students need to learn what is important in communicating with a visual display, they also need guidelines in learning to communicate using words and numbers. "The virtues of a good statistician, therefore, involve …the skills of a good storyteller. As a good storyteller, it is essential to argue flexibly and in detail for a particular case; data analysis should not be pointlessly formal. Rather, it should make an interesting claim by telling a tale that an informed audience will care about, doing so through an intelligent interpretation of data." (Abelson, 1995). This paper primarily addresses strategies to help learners develop the ability to tell a story about the results of a statistical analysis in language accessible to an audience unfamiliar with statistics and the challenges in helping students develop this skill. The emphasis is on preparing both consumers and producers of data, particularly those charged with telling a story to others when given data.

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THE STUDY

The study is based on a research project carried out in a semester-long (15 weeks) statistics course for students in an elementary teacher preparation program at a large midwestern public university who had selected a mathematics emphasis for their certification. Over several iterations of the course, data were collected from students who gave permission for their work to be used in the study. Overall, 67% of the students had never taken a statistics course; 10% had taken an introductory university course and the others had taken some statistics in high school. The semester-long class met twice per week in 110-minute sessions. The project was designed such that learnings from one iteration informed the next. Students had their own computers and used TI© Nspire software to access files from *Building Concepts: Statistics and Probability* (https://education.ti.com/en/building-concepts) and later StatKey (www.lock5stat.com/StatKey/). The goals of the course were to enable students to interpret and make sense of data, in particular data related to education, and to give them tools and strategies for their own teaching. The study is retrospective in that the original research goals did not directly focus on communication. Rather, the original focus was research related to interpretation skills that demonstrated whether a student understood a concept and not communication skills that involve sharing the information clearly with others (Rumsey, 2002).

During the first iteration of the course, it became apparent that students were used to communicating mathematics with symbols and few, if any, words. When asked to describe a distribution from a graphical display, it was common to see responses such as: median = 22; mean = 15; mode = 18; range = 40; UQ = 32; LQ=9; IQR = 17. Context was irrelevant, and the only words used were labels for the numerical values. Students were unhappy when such responses were criticized as they were "right" from a mathematical perspective. To address this, in the following iteration of the course, students were assigned to read several short articles (e.g., Franklin et al. 2007; Scheaffer, 2006; Rossman & Chance, n.d.) on the difference between mathematics and statistics followed by a class discussion about what this difference would mean with respect to the work they were going to be doing in the course. This was successful in that students no longer were resentful when their work was criticized for lacking context, although more had to be done to help them understand what good writing should be. To provide a more formal analysis of the issues with student writing across the course, this paper explicitly explores the questions: "What constitutes a good story based on a set of data?" and **"**What strategies can be used to help students develop the ability to write good stories describing a set of data?" As a precursor to finding ways to develop students' ability to write a good story, it seemed important to determine characteristics of a good story. This was approached by explicitly analyzing student responses from this perspective, and the results are discussed below.

METHOD

The data consisted of responses from 23 students in the second cohort (Institutional Review Board permission was not in place at the beginning of cohort 1) to questions from tests and quizzes, lab reports, teacher notes, and lesson plans. A reductive approach to analyzing the responses by way of inductive category formation (Mayring, 2014) was used to identify characteristics of student writing. The analysis began with open coding of responses to relevant test items by both authors, consistent with an open coding technique drawn from grounded theory (Strauss & Corbin, 1998). Emergent coding (Lazar et al., 2017) was used to note interesting facets of student responses to questions asking for descriptions of a distribution of data on the first test and the final examination. Table 1 identifies the major themes emerging from the analysis. We used these to define the problem of writing descriptions that clearly explain statistical information and ideas to an audience without extensive statistics education along with examples for each component that support the relevant descriptive properties. The coding was primarily done on the first test, but revisited in the responses on the final to capture details that did not emerge in the first round of coding. Writing good stories is dependent on a solid understanding of statistics (Parke, 2008). Because the focus was on written communication of a statistical analysis, responses that contained conceptual or statistical missteps such as confusing a quartile with an interval, describing maximum or minimum values as outliers, or assuming knowledge of the shape of a distribution from a box plot were included in the coding but are not part of the table.

Context as used in the analysis is the background information that provides an understanding of what the numbers represent; language refers to the nature and usage of the words in the writing; interrelationships refers to the way the ideas such as "shape, center, and variability" are linked or put together; and connections relates to the use of verbal, symbolic, and graphical representations to jointly develop meaning. The tasks involved describing dot plots of pulse rates before and after exercise, dot plots of arm spans, a histogram of monthly earnings of a company's employees, creating a graph for the mean income of countries in North America and describing the distribution, and using box plots to compare the length of time students of different age groups can stand on one leg.

Table 1. Characteristics of a good statistical story

Characteristics	Problematic Responses	Appropriate Responses
Context	Ignoring the context ("the data")	Connecting to context ("the distribution of pulse rates…")
	Not being specific ("two points"; "lowest value"; "on average")	Stating in terms of context ("two countries with the highest incomes"; "the lowest pulse rate…")
	Not anchoring numbers ("an IQR of 14 shows a lot of variability" or "shows little variability")	Grounding the numbers to make sense ("the rates went from 64 to 106 bmp, so an IQR of 14 is not much variability")
	Not connecting numerical results to the context ("the median was 85")	Integrating the context ("half of the class had pulse rates below 85 beats per min")
	Struggling with or omitting units ("the mean income is between 150 and 40 hundreds of dollars")	Attending to units appropriately ("the mean income is between $15,000 and $4,000 ")
	Overly general observations ("employees typically earned one of two common salaries")	Bringing in context knowledge to enrich story ("The company seems to have two kinds of employees-managers with high salaries and workers with low salaries")
Language	Overly technical ("US and Canada are outliers in incomes and plot of incomes is skewed right with Trinidad third")	Using more friendly words ("US and Canada have incomes at least twice as large as others; those in Trinidad, 3rd, make 50% less than US and Can ")
	Using jargon or colloquial words ("the distribution [of pulse rates] moved up…")	Using easily understood words ("after exercise, everyone's pulse rate increased")
	Using a statistical term without the technical meaning ("The difference was significant")	Avoiding technical terms in general ("The distributions of incomes differed with respect to…")
	Using a statistical term slightly incorrectly ("the plot has two ranges" ; " the shape is modal"	Correctly using terms ("the two most common weights were…")
Interrelationships	Using measures of center without corresponding measures of variability or vice versa ("Half of the students could stand on one foot for 92 seconds")	Using both measures of center and variability ("Half of the students could stand on one foot for 92 seconds but typically they could stand anywhere from 46s to 120s-the IQR")
	Compounding numbers/percentages ("74% of 23%…")	Using words instead of percentages ("Almost three-fourths of the 23%…")
	Not comparing when asked to compare ("25% of 12 and older stood on one leg between 0 and 75 seconds, and the bottom 25% of 10-11 year-olds could stand on one leg between 10-65 seconds")	Identifying differences/similarities for groups ("There was a 10% difference in the length of time the bottom 25% of students in both age groups could stand on one leg, up to 65 seconds for 12 and older and to 75 seconds for 10-11 yrs")

	Ignoring potential outliers ("Most of the earnings are between $8,000 and $23,500")	Accounting for outliers ("In the US and Canada, people have much higher earnings than in all of the other countries, about $28,000 more")
	Using only range to describe variability ("There is a big range, from $800 to $52,80")	Using both range and other measures of variability ("The range spanned from $800 to $52,800 with half of the countries having incomes from $4,000 to $15,800")
Connections	Not referring to a visual representation ("It's typical for an 11th grader to have an arm span between 140-190 cm")	Connecting visual representations to words ("most 11th graders had arm spans above 140 cm., but we can see that there is a gap in the distribution, as no 11th graders arm spans fell between 90 cm and 140 cm on the graph")
	Using words without supporting numerical evidence ("majority [of the pulse rates after exercise] fall above previous max")	Connecting numerical summaries and words ("more than 75% of the pulse rates after exercise are higher than 100% of the pulse rates before exercise")
	Using numerical results without words ("the median was $2500")	Integrating words and numbers ("half of the employees earned less than the median, $2500")
	Rambling unconnected sentences	Synthesizing and connecting the key information to tell the story

The next section addresses the second question by discussing some interventions used to support the development of students' ability to communicate in writing about statistical ideas.

INTERVENTIONS

As the course progressed, while students were increasingly comfortable working together, typically in random groups of three (Liljedahl, 2020), and engaging in verbal discussions, the struggle they had with written communication became visible in their responses. This led to a variety of interventions to help students create coherent and meaningful descriptions of the results of analyzing a set of data, but these were not formalized at the time nor were they deliberately designed as part of the overall research. Providing model descriptions of a "good story" had minimal success as students did not seem to internalize what characteristics of the samples made them good models and were unable to transfer the ideas to other contexts and concepts. For example, the analysis of student work from the first test found them often leaving out variability along with other shortcomings identified in Table 1. Providing examples of a description and having small group discussions on "what did you like; what were you concerned about" for the examples seemed to help somewhat, although there were still reminders in later lessons to use shape, center, and variability; attend to outliers; and use both numbers and words in their lab reports.

The use of sentence frames is a strategy often suggested by teachers for enabling students to reply correctly to a question. However, what little evidence there is regarding the success of this strategy is mixed (e.g., Block, 2020), and the frames typically do not support developing students' ability to explain the idea or tell the story in words a non-statistician might understand. For example, some sentence frames merely report the calculation results using technical language: "The__has a median of __and a mean of __. The mean/median of __is smaller/larger than the median/mean of __. The distribution of __ has a mean less/greater than the median which supports the strong/weak skew to the left/right." (https://ranchostats.weebly.com/uploads/1/1/8/5/11853997/ap_stats_sentence_frames.pdf)

Considering findings from formative assessment that suggest written comments along with a grade are of little use in helping students understand what is concerning about their work (Wiliam, 1999), the interventions focused on prompts that would cause students to think. One such strategy was "Why am I worried." After a quiz on using shape, center, and variability to describe several given distributions, a class discussion was held on the prompt: Why am I worried when I read a statement like, "There were more dots in one distribution than in the other so there is more variability in the one with more dots." Or, "The number of samples was 200 in both cases, so the variability was the same."

Another intervention was to mark a "yellow slash" through a phrase or word that seemed inappropriate in a response, then giving students the task of figuring out (individually or in groups of three) what was concerning about the writing (Teaching Channel, nd). For example, "That means that the middle 50% of the states had the Hispanic student graduation rate of 67-77%, which also tells us what is typical for this set of data. The median of the data is 73%, …" Student comments in their reflections suggest that both the yellow slash and what am I worried about were useful strategies (e.g., a typical quote, "it was good to get feedback on homework assignments that is specific so we can learn from our mistakes as well as on test corrections … this was one of my favorite things of the class.").

Peer review (Parke, 2017), particularly for reports and larger writing pieces, was another strategy, although after several experiences in which students praised each other's work without giving constructive advice, the instructor designed a rubric to guide student comments:

> Consider whether the response addresses the prompt and make notes for the author using at least one of the following four statements: The response
>
> a) addresses the topic in a way that is understandable and makes sense because it …
> b) might have more details or clarification such as ….
> c) uses appropriate statistical language although I did not ….
> d) confused me when it said ….
>
> Be sure to give comments you think would be useful for the author in revising the response. Think about what you would like to learn if the work were yours.

This was fairly effective as can be seen by a typical student comment on the process: "Jaya looked over my lab report and gave me feedback about it. This helped me to recognize some mistakes throughout my report and clarify some aspects to help the reader understand it better. For example, I used the word "range" inappropriately, which Jaya pointed out to me. She also explained the r^2 value to me in a way that helped me to better explain its importance to this specific investigation."

Students were given writing tasks such as explain to a seventh grader what the data tell you about the weight of backpacks carried by students in middle school, or write an explanation for someone in your family about the connection between gender and income. While these were subject to comments and discussion, little was done to support student understanding of how to create such stories. Responses to a question describing a simulated sampling distribution on the final exam show that the ideas about good writing did not seem to transfer well to this new context. Extending the work to the next cohort of students may provide more insight into how to help with this.

CONCLUSION

The work has identified characteristics of good data stories and suggestions for different strategies to help students build the skills necessary to write these stories. Ongoing work will investigate whether these strategies have any possible association with changes in the nature of student responses, cognizant that the absence of randomization precludes any cause-and-effect link. The results thus far, however, could provide direction for future research. The characteristics provide a language and structure for thinking about statistical writing that could be useful for those teaching statistics at the school level in designing activities to support the development of student competency in written communication. A limitation, however, is that the tasks analyzed were primarily associated with univariate data and did not include student writing about multivariate data or inference. Expanding the analysis to these areas could either confirm the usefulness of the categories describing writing or suggest ways to adapt/extend the categories to make them more generally applicable.

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