LEARNING TO ADVOCATE WITH DATA IN A MODELLING ENVIRONMENT

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Modelling data can provide students with experiences to develop their understanding of contributing factors to a data-based situation, their ability to offer ideas towards solving a problem, and their written communication around decision-making, argumentation, and advocation for change, a nascent area of research. Motivated by personally relevant societal issues, novice 11-year-old students were introduced to a mechanistic modelling approach using TinkerPlots, with the aim of replicating underlying distributions to simulate phenomena seen in data. Follow Up Tasks to Model Eliciting Activities were used to support and enhance students' statistical writing about their modelling process, and their argumentation, decisions, and recommendations. The findings indicate that students' written communication and advocacy could be improved.

INTRODUCTION

Communicating findings from data and advocating for change in a societal situation has received little attention in research (Burrill & Pfannkuch, 2024). Statistics educators need to take up the challenge of developing students' ability to communicate and understand findings based on data in a world awash with misinformation and disinformation. Teachers in other disciplines, generally, do not have sufficient knowledge about data-based evidence to combat "fake news". Therefore, statistics educators hold a unique position and responsibility in education to assist students to critique others' statistical findings and to write about findings from their own investigations. Writing and learning are seen as complementary activities (Brookshire & Brundage, 2015), however, more opportunities need to be given to students to develop their written communication in the statistics classroom and to communicate and argue for potential solutions (e.g., Souza et al., 2020). In this paper we explore novice students' development in communicating their findings about problematic situations in a modelling environment, where they built chance-based mechanistic models of a real-world situation relevant to their school, and then explored "what if" situations by adapting their models.

LITERATURE REVIEW

Statistical models can take many forms: they can be graphical, inferential, experimental, or predictive in nature. Whatever form they take, Cobb and Moore (1997) explained the need to weave together the data context with the analysis to illuminate for the reader the most interesting aspects of the story: "In data analysis, whether the patterns have meaning, and whether they have any value depends on how the threads of those patterns interweave with the complementary threads of the story line" (p. 803). Because every data-based situation begins with messy real-world data that undergoes a unique modelling process, statistical writing about models useful for prediction, involves communicating complex ideas about real and simulated data distributions, and what these mean for proposed changes to a situation. Although Stromberg and Ramanathan (1996) contended it is "both easy and vital to include writing in the general statistical curriculum given the interdisciplinary nature of the subject" (p. 161), communicating the story line of a unique modelling process means deciding which data-based insights and possible solutions to present to a range of audiences. Students not only need to develop their technical language, but also their ability to write in plain language for a general audience. Recognizing this is not easy, Beins (1993) concluded that students who wrote about statistics in plain language acquired better interpretative and computational skills. Grossman et al. (1993) commented that "writing [about statistics] becomes the means for translating the strange into the familiar and the seemingly foreign or new concept into a comprehensible or understandable idea" (p. 2). Furthermore, having students write in mathematics classrooms has been used to enhance students' metacognition: students write to describe and reflect on their strategies, and to plan ahead when solving problems (Pugalee, 2001; Yoon, 2017).

Like any good story, the beginning sets the scene, with an explanation of the problem to provide the reader with an understanding of the current situation. Writing about data and models is a complex

In: Kaplan, J. & Luebke, K. (Ed.) (2024). *Connecting data and people for inclusive statistics and data science education. Proceedings of the Roundtable conference of the International Association for Statistics Education (IASE), July 2024, Auckland, New Zealand.*

skill as it is telling the story of the enquiry cycle in which ideas can evolve, some of which are communicated, while others are dropped (Wild & Pfannkuch, 1999). In a mechanistic modelling process the writing should explain how causal factors were identified and their distributions investigated to gain an understanding as to what could happen to bring about necessary change in a system. The process of modelling data involves many design choices, such as, which measures to collect, how to categorise data, and which aspects about the process and findings of a data-based investigation to highlight for an audience.

One approach for enhancing students' writing is through Model Eliciting Activities (MEAs), which are a class of modelling activity that mimics the kinds of modelling practices encountered by statisticians (Lesh et al., 2000). These educational activities emphasise both spoken and written communication by having students work together, in this case, to build and use *chance-based* models to develop their understanding around underlying or *causal* factors that contribute to phenomena seen in data. More importantly, MEAs offer the experience of statistical writing and argumentation around a possible solution(s) to a real-world problem. Students complete MEAs by writing a letter to a client, suggesting a potential solution to their problem. During MEAs students typically engage in verbal discussions, but they often struggle to write their ideas in a letter to a client, due to a lack of experience with communicating their model findings (Yoon & Patel, 2011). They also struggle to document their models and modelling process, so that others may critique these and their model-based findings. MEAs can support student writing about models and modelling processes, through their self-referent, self-checking design principles (Lesh & Doerr, 2003). Statistical writing should ideally communicate to the reader a balanced view of both the data and modelling process. For example, how the real data was collected and modelled, and the compromises, assumptions, and limitations made in order to reveal the story about what the findings and recommendations mean in context.

As part of a larger study, Patel (2022) developed a Statistical Modelling Processes (SMP) framework, one element of which, *making decisions and communicating*, outlined the aspects one would expect to find in a comprehensive report for a statistical modelling investigation (Figure 1). The element was considered aspirational in that it could be a guide as to what novice students could work towards. For this paper our research question is: How can novice students' statistical writing and advocacy be improved?

Making decisions and communicating

6. Communicating findings and recommendations (Model world–Real world)

6.1 Stating background to problem.
6.2 Making model informed decisions, specific problem solved and enumerated with statistics in context.
6.3 Recognizing effects of underlying randomness in multiple simulated data distributions. Range of outcomes (e.g., confidence intervals, model fit, uncertainty) with respect to simulated data variation communicated.
6.4 Stating and conjecturing pros and cons of decisions and wider implications of recommendations.
6.5 Stating limitations and assumptions underpinning model.
6.6 Deciding what and how to communicate findings (e.g., summary statistics, percentages or count, positive or negative framing of situation, order of argument). Choosing what features to communicate and how to present these coherently.
6.7 Using models to explore problem further in context. Posing then modelling and exploring realistic "what if" scenarios that may produce recommendations to resolve the problem.

Figure 1. Communication element of the SMP framework (Patel, 2022, p. 157)

METHODOLOGY

As part of a two-year design-based research study, six 11-year-old students, from a mid-socioeconomic school, worked in pairs during twelve two-hour sessions. The first author devised and delivered the sessions, composed of MEAs and associated Follow Up Tasks (FUTs). *TinkerPlots* (Konold & Miller, 2011), which students had not encountered before, was used by pairs of students to analyze the real data and to model the data. Students' interactions with *TinkerPlots*, including letters written in text boxes and conversations between students, were captured with Camtasia. To answer the research question, a description is given of the development of two pairs of students' letters to their client for their first MEA, in FUTs designed to improve their communication and argumentation, and in their final MEA. During both MEAs I (first author) refrained from giving explicit suggestions to the students to enable them to develop their own chance-based models and write their own letters to the client. The first MEA occurred in the final session of the first year of the study, the communication

FUTs in the third and fourth sessions of the second year of the study, and the final MEA in the sixth and final session. Student letters written in one of the FUTs and the final MEA are analyzed using Figure 1.

DEVELOPMENT OF STUDENT COMMUNICATION

The Bag Weight MEA

For the Bag Weight MEA, students were given a media article about a study conducted on New Zealand school students, which warned that many students were carrying backpacks that were too heavy for them, resulting in back pain. It recommended students should carry no more than 10% of their bodyweight. Because the school had recently become a BYOD (bring your own device) school, the students were required to find out for the principal how many students in their school were likely to have bag weights over 10% of the average weight of an 11-year-old, and what the effect would be if the requirement for BYOD was dropped. The students then collected data on bag weights from their class to produce a distribution in *TinkerPlots*. Using the Sampler tool in *TinkerPlots* (e.g., Konold & Kazak, 2008; Pfannkuch et al., 2018), they constructed a model with contributing factors such as books and devices, for which they constructed distributions based on data they gathered about the factors from what they found in their backpacks (Patel & Pfannkuch, 2018). Using Google, they derived the average weight of an 11-year-old. Once they were satisfied the simulations showed their model mimicked the real data distribution, they created the same model without the device distribution and hence could compare backpack weights with and without devices. During the modelling process they wrote a letter to the principal about their findings. No instructions on how to craft the letter to the principal were given, such as framing, evidence, and justifications.

In response to the media article about students carrying overweight school bags, the students discussed whether their own bags were over or under the recommended weight, with Dan claiming he agreed with the article's sentiment about overweight bags contributing to back pain: *This is happening to me! Pain in my shoulders and upper back. The pain, the pain!* Nico also shared his personal situation: *My sister, she always gets me to carry her school bag when we walk down the driveway, and it's really, really heavy, and also my swimming bag in the morning is a lot heavier than it should be.* Such comments about the context at the beginning of the task helped anchor and connect the students to the problem and provided an incentive and a rationale for completing the task. For example, Dan commented: *Are we actually going to give this (letter) to the principal?* When writing, they argued about whether the letter should be positively or negatively framed. Dan argued for a negative frame and that they should write, *almost half the students in the school have bags that are too heavy for them*, whereas Nico wanted a positive framing. The final sentence was added in their letter only after I asked them to enumerate the reduction in average bag weight by using their model (Figure 2).

Dear Mr Todd if you look at our plots your will see that 376 students in the school have bags that are suitable for them to wear. If our school was not BYOD then 636 students would have suitable bags. It would be much better just have school devices and no one brings a device to school but maybe we would be allowed a phone to use as a contact device. Dan has a conspiracy theory that boys are getting shorter because of having heavy bags. technology is getting more advanced and more heavy and people want new technology which leads to heavy bags. Without a device the average is almost 1kg. Yours sincerely Nico and Dan
Dear Mr Todd, Roughly 365 or 54% of your students have bag weights that are over 10% of their average body weights. This is not good and is over the reccomended standard weight. Without devices, roughly 87 students or 13% have overweight bags. Ali and Leo

Figure 2. Student letters to their principal on the bag weights in their school

Nico decided on a positive frame, even though the task specifically asked for the number of students with overweight bags. They were aware there was more than one answer for the number of under or overweight bags, however they chose to communicate a single number, rather than state the uncertainty in the data. For example, they could have stated, "about 5–7 percent of students will have overweight bags if devices are not allowed" as they had seen and articulated during simulations. Therefore, this aspect of variation was missing from their letter, possibly because they believed that mathematics requires single answers. Ali and Leo, however, did communicate uncertainty in their letter through use of the word *roughly* (Figure 2). Nico and Dan also provided a recommendation for how to reduce bag weights, and an implication, albeit a non-evidenced-based student one, about their recommendation. As expected, these novice modelers produced letters that lacked important aspects of the modelling process, and critical aspects in their findings and inferences (Figure 1).

FUTs

The student Bag Weight MEA letters were crucial artefacts in the design of the FUTs as they indicated what was important to these students to communicate about the modelling process in their writing. Armed with this knowledge of students' letters, we developed FUTs linked to the Bag Weight MEA focused on communicating statistical findings. To assist the students, we developed a communication framework with 10 features (Figure 3). I wrote an exemplar bag weight letter to the principal, which students read and commented on. The students identified features in the exemplar letter, and then in their own Bag Weight MEA letters against the communication framework.

Communication Framework

1. Why did they do the investigation? (Background, rationale)
2. How did they do the investigation? (Method)
3. What did they do to solve the problem? (Model construction)
4. What did they find? (Findings/Predictions)
5. Can the findings be trusted? (Model Fit/Real data quality)
6. Was a range of outcomes given in the findings? (Prediction interval)
7. Were theories, beliefs and best guesses used to build the model given? (Assumptions)
8. Were there restrictions given about when the model should and should not be used? (Limitations)
9. Were suggested improvements about the situation given? (Recommendations)
10. Were the pros and cons of the recommendations discussed? (Implications)

Figure 3. Communication Framework

To help students write about each feature, Bag Weight scenarios were given to them, to learn, for example, how to produce an average from the simulations, and how to consider other factors to reduce the weight of backpacks rather than the devices. As a final practice of writing a letter, we drew on the findings from the Bag Weight MEA media report, which stated that Year 9s (13-year-old high school students), were carrying their backpacks around school all day because lockers were not provided for them, whereas Year 8s (12-year-old intermediate school students) have home rooms. Using data on bag weights for Year 8s and Year 9s from CensusAtSchool, the students adapted their models to mimic the real data distributions, and then wrote a letter (e.g., Figure 4).

Dear high school principal,
we have noticed that your school has a large number of year 9s have overweight bags (6.1). A total of between 40% and 55% of year nines at your school have overweight bags, where as only 30% to 38% of the year 8s from the intermediate have overweight bags (6.3). (we know this because we made a model that replicates some of the items that would be in your students bags. this included: (food, clothes, books and water). once we had finished making our model, (the averages proved a lot of things, the year 8 average ranged between (3.7kgs and 3.8kgs whereas the year nine bag weights ranged between 4.3kgs and 4.6kgs which is significantly higher (6.2, 6.3). this is a problem that needs to be fixed and the ways to fix it lies in our data. we found out that what affects our data most is the difference between the amount of water that the students bring. the year 9s on average bring a lot more water to school than year 8s (6.6, 6.7). (we think that the way to solve this is by installing more drinking fountains around the school and making water a lot cheaper at the canteens (6.4). we also think that vending machines should be added around the school. we know how bad this problem is and we want to try do everything we can to stop it.

Figure 4. Ali and Leo's letter to High School principal

Compared to their Bag Weight MEA letter (Figure 2), Ali and Leo have woven a much fuller coherent story about their findings on overweight bags for Year 8s and Year 9s, including a recommendation based on their models. Apart from limitations (6.5), they touched on all aspects of the communication element (Figure 1) including giving a range of outcomes for the 10% threshold and the average. Although one might query their findings and assumptions about the amount of water brought to school by Year 9s, they seem to be learning how to argue and advocate for improving the situation of overweight bags by using student-based contextual knowledge.

The Homework MEA

Students read a media article expressing concern that New Zealand students were spending too much time each week doing homework compared to the OECD average and that girls on average spent more time on homework than boys. They were told the principal was concerned about these findings and he wanted them to (1) survey students in their class to find out the number of minutes they spent on each subject's homework per week, including the total number of minutes; (2) build a model of the current situation; and (3) build another model to develop a more effective strategy to ensure students were doing no more than 3 hours of homework per week.

Before Nico and Dan wrote their letter there was a lot of discussion about understanding the survey data, putting forward reasons as to why a particular datum seemed to be an outlier, why some subjects such as science were not set homework in the survey week, deciding what reductions to make in each subject area such as reducing mathematics from a distribution ranging from 0 to 140 minutes per week to 0 to 30 minutes to ensure the total homework minutes per week did not exceed 180, and how to reduce the homework load. Their final letter is in Figure 5.

> Dear Mr Principal, we are writing to you about homework The reson why we did this is to find out if the amount of homework students get is reasonable, also we read an article that got us interested (6.1). The current homework situation is on average boys are doing 200 minutes total a week and girls 560 minutes total a week. However most boys did next to no homework but a few boys did a lot bringing the average up (6.1 & 6.6). We built a model using tinkerplots and we recreated the real data, but when we made the model we did not include one piece of information because it was 500 minutes under technology and we think they though it was how long they used a device (6.5 & 6.7) Some restrictions we had when building the models was some information could have been false, we only surveyed 25 people and only 9 of them were girls so we didn't have enough people (6.5). We have some improvements and here are some we think that would work. We could give out less homework so that students don't spend as long doing homework or we could give out homework that is sutible for the students level, for instants give the stupider kids easier homework so they don't struggle therefore spend less time on it (6.7). When we put this into our sampler, the results dropped druastically. Boys average going from 229mins to 92 mins, and girls dropped from 308 minutes to 104 minutes (6.2 & 6.6). Boys dropped 137 minutes and Girls dropped a total of 204 minutes, that's amazing (6.2 & 6.6). However, if there is less homework and easier homework then the students may not be revising enough (6.4). but still we recommend that you give out easier homework and less (6.7). We think that people took a long time for homework because it was too hard and therefore taking them longer, or they had too much homework and they didn't want to get in trouble so they finished it anyway. Also some people might have thought that the technology column was for the use of devices (6.5). In conclusion we deffinatly recommend that you give out homework suitable for the students so it's not too hard and give them the appropriate amount too. We highly recommend that you instruct the teahers to hand out more suitable and customized homework for all students (6.2 & 6.7).

Figure 5. Nico and Dan's letter to their principal on homework time per week in their school

In their letter Nico and Dan reflected coherently on their modelling process and weaved in the main insights from modelling two homework situations, the current one and the proposed one, covering all aspects of the communication element (Figure 1) except 6.3, range of outcomes, communicating variation. They reasoned using summary statistics to compare groups, that is, the differences between means of two chance-based conditioned simulations, to communicate changes and differences in the two situations. In their conversations they were aware of variation between simulations but did not include that information in their letter as they used single values rather than intervals for summary statistics. Noteworthy was that they mentioned a limitation of their model (6.5): the sample size in the survey was too small for girls. Because they included their models (not shown) with their letter, they seemed to assume their client, the principal, could see the reductions they made in time per week for each subject to ensure total homework time was a maximum of three hours and hence did not discuss them. Nico and Dan's letter indicates they seem to be learning how to advocate for changing the homework situation in their school based on statistical modelling. They weighed the pros and cons of their recommendations and argued and gave voice to their perspective. Overall, compared to their Bag Weight MEA letter (Figure 2), their letter indicates that after the FUT experiences and use of the communication framework, what and how they wrote about their modelling process improved, resulting in some coherent findings and recommendations.

CONCLUSION AND DISCUSSION

These students' writing has been characterised through the SMP framework communication element (Figure 1). The findings of this small exploratory study cannot be generalised and remain as conjectured reasoning processes and actions. From the analysis of these students' writing there are indications they were developing the ability to reason and write about (1) phenomena and data in the real world and the representation of underlying factors of the phenomena for the observed variation in the model world; (2) representativeness of samples, and its role in model building; (3) uncertainty in simulations and how to deal with uncertainty and communicate it; (4) ranges of real and chance distributions through integration of contextual and statistical knowledge; (5) simplifying assumptions to build models and recognizing models have limitations; and (6) communicating findings in context. Challenges remain for considering further explorations, including how to argue for change in school policy and to suggest possible solutions based on "what if" scenarios conducted in the model world, and to continue the enquiry process such as hypothetical evaluations of possible suggested changes.

Our study considered students' statistical writing, including their decision making and argumentation using models and modelling processes, to be an important competency students need to learn alongside statistical concepts and processes, not just in service of it. The aspects of the SMP framework communication element (Figure 1) are not exhaustive and were not demonstrated by all students, and with varying degrees of success. They provide aspirational writing aspects one would expect to see in a formal report. If students are to understand that different starting values, assumptions, simplifications, and inferential limitations lie behind models that affect model outcomes, then it will be necessary to give students experiences building and using models and communicating to others about their models and modelling processes, thus engendering skeptical rather than cynical dispositions that foster critical thinking about model-based data. Enhancing written communication of statistical concepts in plain language also allows students to become better consumers of statistical information as it allows them to evaluate arguments critically based on data and models (Ridgway, 2022) and to advocate for changing a societal situation based on findings from statistical investigations (Burrill & Pfannkuch, 2024). To enhance student ability to advocate, we contend the Bag Weight and Homework contexts were personally relevant to students and the purpose of improving a known problematic societal situation in their school was very clear to them, resulting in their engagement and willingness to advocate for change (cf. Souza et al., 2020). Their letters, however, would have had more relevance if the principal was included as a participant in the study.

The act of marshalling, framing, and making your thoughts public, by writing down arguments for and against ideas and decisions supported by data analysis, should not be an "inert record…judged on the number of correct facts it contains… It is also a rhetorical act that seeks to engage" an audience and tries to persuade and "inspire some kind of response or action" (Yoon, 2017, p. 33). Learning about advocacy using findings from data, however, requires drawing students' attention to ethical data practices through all stages of the modelling process from data collection to communication (Tractenberg, 2023). We demonstrated improvement in these students' written communication but realize that more can and should be done to support student statistical or formal writing over their time in education. Writing is not only a means to promote and cement their understanding of complex interconnected statistical concepts such as distribution and model fit, but also as a competency to promote in its own right, so formal writing, involving data-based descriptions, predictions, and decisions by themselves and others, can be critiqued and their argumentation abilities improved.

Students need support and exposure for creating and interpreting statistical writing, including generalization, abstraction, elaboration, objectivity, authority, logic, and flow (Fang & Park, 2020). Our study showed that students began with everyday writing registers, which began to include conventional statistical language, as they experienced variation, model fit and uncertainty in their use of models. To enhance student communication and advocacy, there is a need to support correct and greater use of formal language in terms of the modelling process and findings, whilst simultaneously keeping hold of everyday language to connect with a general audience. We concur with Samsa and Oddone (1994), who after teaching a course in statistically based scientific writing, concluded that "writing is an excellent mechanism for identifying students' strengths and weaknesses" (p. 119) because writing exposes what students can and cannot explain, it also helps us discover what they still need to learn and the support and experience they need to learn it.

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