HOW REPRESENTATIONAL MEDIUM AFFECTS THE DATA DISPLAYS STUDENTS MAKE

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We compare two methods of recording data and making graphic displays: a standard paper-and-pencil technique and a "data-cards" approach in which students record case information on individual cards which they then arrange to make displays. Students using the data cards produced displays that tended to be more complex and informative than displays made by those in the paper-and-pencil group. We explore plausible explanations for this difference by examining structural aspects of the two approaches, such as the saliency of the case and the use of space in organizing the information. Our results call into question the wisdom of the current practice of introducing young students to particular graph types and of the idea that they need to master handling of univariate data before they move on to multivariate data.

INTRODUCTION

Tukey's (1977) informal plots, such as the stemplot, aimed to provide statisticians with a set of informal tools that they could use to quickly explore data by graphing them. They enabled a statistician to gain an initial understanding for what data might be able to tell by revealing patterns that otherwise may have gone unnoticed.

In comparison to more standard displays, such as the histogram, Tukey's plots minimize data handling. Data are often sorted rather than counted, and with the stemplot, data can even be graphed at the same time they are collected. It is important to remember that Tukey designed these techniques before computers became widely used for graphing and analyzing data. Of course, computers now take over the laborious work of graphing, but students first learning how to make various plots, including some of Tukey's, still typically do them by hand.

It is paradoxical that several of the techniques Tukey introduced to empower statisticians to flexibly explore data are now typically introduced to young students as just additional graphs to learn how to make (Bakker, Biehler and Konold, 2005). Our sense is that as students work to learn how to make and interpret these displays, they seldom experience the informal, exploratory use of them that Tukey had in mind when he created them.

It was a vision akin to Tukey's that inspired the creation of *TinkerPlots* (Konold and Miller, 2005), a data-analysis software tool for middle school. The intension was to give students an intuitive, informal set of operators that they could use to flexibly organize data to see patterns in them — explorations that they could perform without necessarily having to first learn to make and interpret a standard set of graph types.

With TinkerPlots, students manipulate case objects in a plot window using operations similar to those they would use if they were organizing physical objects on a flat surface: separating them into groups, ordering them, stacking them. Early in the design of the *TinkerPlots* interface, the developers (which included Konold) conducted informal studies of these physical operations. They gave students a set of 20 - 30 "data cards" and then watched as the students arranged the data cards on a table to answer questions they posed. The data cards were small enough to easily arrange into graph-like displays, but large enough to contain all of the attribute values for a particular case (for example, a student's height, weight, gender, and age).

When introducing students to data analysis using *TinkerPlots*, one of us (Harradine) has begun by having students investigate some question and the related data set by first making representations using physical data cards. The hope has been that by having students first focus on what they do in this off-computer task, that the design and functioning of *TinkerPlots* will make more sense to them when they move on to it.

In both of these contexts, our sense was that students behaved differently when using physical data cards to make plots than they did when drawing graphs using paper and pencil. The representations they made with the data cards were often more complex than what we were used to seeing with paper and pencil and the students seemed to have little difficulty attending to and representing more than one attribute at a time, even though they had not yet "learned" how to do so.

The possibility that the representational medium students use might influence their ability to represent and explore multiple attributes is intriguing. Ridgeway, McCusker, and Nicholson (2005) have recently observed that statistics education of young students in the UK "focuses on a narrow range of techniques applicable to only univariate and bivariate analyses" and that it ignores "multivariate realistic problems (which students can actually solve)." This narrow focus, which certainly is not unique to the UK, is regrettable, because it precludes engaging students with many problems that they might find interesting and relevant only because we have not yet introduced them to particular techniques. Our informal observations suggested that by changing the medium in which students work with data, we could facilitate their ability to think about and explore more complex situations. We designed this study as an initial test of these informal observations.

STUDENTS

Twenty students, ten of each gender, were randomly selected from all the Year 7 and 8 students (ages 12 – 14) in one school in South Australia to participate in this study. The school, which serves students from school entry to pre-university study, is one of three serving a rural community on an island just off the coast of South Australia.

TASK DESCRIPTION

Many youth game parlors in South Australia include a game called *whac-a-croc*. The whac-a-croc machine is a hybrid electronic-mechanical device from which five crocodiles move out of small enclosures goading the player to whack them with a soft mallet (see Figure 1). Sometimes one crocodile will move out; sometimes two or three will move out simultaneously. The player gains points for a whack and losses points for a bite (if the crocodile retreats back into its cave before it is whacked). At the end of the game, players receive tickets that they can accumulate and redeem for a small prize.

Figure 1: The whac-a-croc machine.

We told the students that we wanted to make a computer version of the whac-a-croc game and therefore needed information about how the crocodiles *came out*. Their task was to study actual data from the game and make a display that would help us develop a realistic computer version.

We chose this task for several reasons. First, the context is of genuine interest to students of this age. All of the students in this study had, in fact, played the game before. Second, the task calls for more than making simple frequency graphs. The game involves multiple attributes including time dependencies. Even a fairly simple description of the game would require capturing some of these dependencies. Finally, we expected that the students would perceive the task — developing an analysis of the game for the purpose of recreating it — as a genuine, rather than contrived, problem.

Each student viewed a movie showing one of five different game sequences of whac-a-croc we had previously videotaped in a game parlor. Their first task was to code the movie with respect to the following three attributes, which we had defined and described to them.

- *Whack opportunity (WO) number*. The event of one or more crocodiles appearing was defined as a whack opportunity. WOs were numbered based on their order of occurrence.
- C*roc ID*. The letters A to E where used to indicate which crocodile appeared, with A specifying the left-most crocodile when viewing the machine from the front.

- *Appearance form.* The crocodiles could come out as part of a single, double, or triple event.

After coding the data, we asked students to "make a display, on the large piece of cardboard you have been supplied, that will give me as much information as possible about how the crocs come out so that my game works the same as the real one." Students had approximately 30 minutes after coding the data to make the display they thought useful.

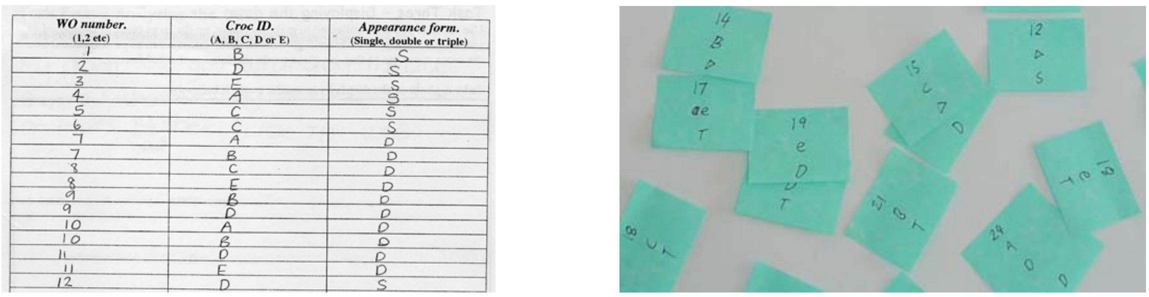
After making their displays, we asked students to write down what the display they made 1) told them about how the crocodiles came out, and 2) did not tell them of what they needed to know. Students who judged their displays as deficient in some way were given the opportunity to modify their plot so as to include the additional information they needed. The opportunity to revise their displays occurred in a second class period, three days after the first. Thus, two, ninety-minute class periods were devoted to the entire activity.

PLOTTING THE DATA

The main objective of the study was to compare the performance of students using two different methods of coding and plotting the data. Accordingly, two groups of five boys and five girls were formed through random assignment: a *Traditional* Group and a *Data Card* Group.

The Traditional Group was directed to record the data in a row-by-column format, with each case listed in a separate row and the three attributes in separate columns (see Figure 2). Based on these data, the students were then to make a display according to the criteria above. Though we did not specify it, we assumed that all of them would make displays with paper and pencil and would employ any knowledge they had about what representations might be useful based on prior instruction in making and interpreting data displays.

The Data Card Group was directed to record data on sticky notes, small square pieces of paper with one under-edge having a sticky surface (see Figure 2). One sticky note corresponded to one case, or one row in a traditional tabular display. To make their displays, this group was instructed to use the sticky-notes and the large piece of cardboard that we provided.



WO number. (1,2 etc)	Croc ID. (A, B, C, D or E)	Appearance form. (Single, double or triple)
1	B	S
2	D	S
3	E	S
4	A	S
5	C	S
6	C	S
7	A	D
7	B	D
8	C	D
8	E	D
9	B	D
9	D	D
10	A	D
10	B	D
11	D	D
11	E	D
12	D	S

Figure 2: An extract from one of the student's tabular collections (left) and a selection of sticky notes from another student's collection (right)

RESULTS AND DISCUSSION

The displays that students produced ranged from simple frequency graphs of one attribute to time-series graphs incorporating three attributes. Figure 3 shows a display produced during the first class session by S14 of the Data Card Group. This is a particularly powerful display. Without explicitly including the third attribute, Appearance form, it is nevertheless easy to see the occurrence of single, double, and triple events by sighting up the columns of WO number. In our judgment, this display type was the most informative given the task objective. Frequency graphs of any one of the single attributes were the least informative.

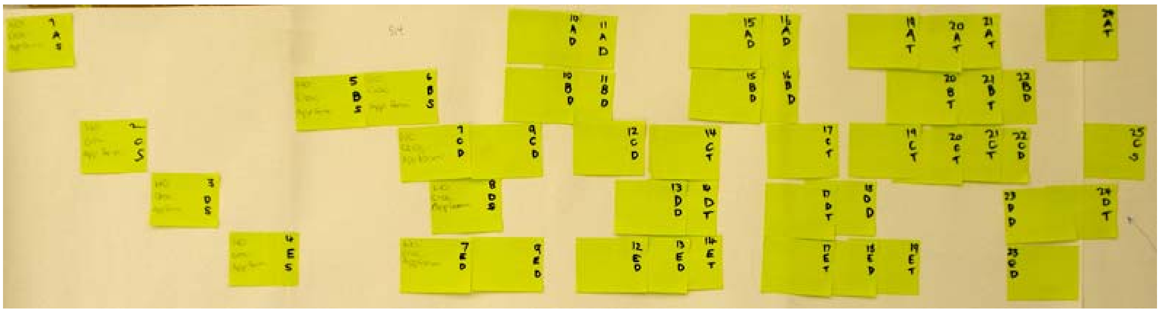


Figure 3: A display made by S14 of the Data Card group. The sticky notes are arranged horizontally according to increasing number of WO and vertically according to Croc ID. As she worked her way towards the right of the display, she began overlapping sticky-notes to fit them all on the paper.

As a first-order indicator of the differences in display types, we coded students' initial displays with respect to two aspects: 1) whether they were uni- or multidimensional, and 2) whether they explicitly incorporated WO number. Of the 10 students in the Data Card Group, 9 made multivariate displays that included WO, compared to 3 of the 9 in the Traditional Group. [We omitted from the analysis one student from the Traditional Group. This student drew a frame-by-frame animation of the video, which we were unable to categorize.] Of the remaining 6 students in the Traditional Group, 2 made graphs including both Croc ID and Form, and the other 4 made single-attribute displays of either Form or Croc ID. The remaining student in the Data Card Group, S11, made a frequency graph of Croc ID (see Figure 4).

Figure 4: A frequency graph of Croc-ID made by S11. This was the only single-attribute plot made by a student in the Data Card group.

Taken together, these results provide compelling evidence that the method of representing and plotting the data affected the informational quality of the displays students made. A Chi Square comparing the two groups with respect to whether they were able to represent multiple attributes and WO number in their graphs was significant (6.54, $p = 0.01$).

Generally, it was the illustration of time dependencies in the plots of the Data Card Group that made their displays more informative than those of the Traditional Group. This raises the question of why the time-based attribute, WO number, was almost always represented in the graphs of the Data Card Group but less frequently in the Traditional Group. The effect could result in part from the fact that with the sticky notes, the case is always evident. The saliency of the case may help students stay better grounded as they are making a display, helping them to maintain their sense of the information it conveys (Feldman, Konold and Coulter, 2000). This grounding may also help them note deficiencies in their graphs and prompt revisions.

There is no evidence in this study that case saliency explained the difference between the groups. In fact, it seemed from the descriptions students wrote of what their displays did and did not convey, that students in the two groups were equally able to interpret and evaluate the displays they had made.

Another possibility is that with sticky notes, students can opt to use physical space rather than formal axes to organize the data. They can organize the sticky notes in small steps using simple actions such as separating them into groups and ordering them according to the value of one of the attributes. These actions require less forethought than having to create formal axes and they produce results that can be easily modified or extended; sticky notes that have been stacked up can then easily be reordered according to the values of an attribute. Also, should a student attend to only one attribute in making an initial representation, the information from the other attributes is ready-at-hand on the sticky-notes to use in making a more informative display.

Finding supporting evidence for this conjecture would require documenting and analyzing the actions of individual students as they create their plots, which in this study we could not do. We did, however, observe closely one student whose behavior offers some support for this explanation. After making the plot shown in Figure 4, (S11) considered what the plot did not tell him that he needed to know, noting specifically that it did not display WO number. In the second class period, he was given the chance to revise his display to include this additional information. We observed him first arranging the cases within each ID group in ascending order of WO number. We then asked him if it was possible to display the WO number in a clearer manner. This prompted him to space the sticky-notes out vertically according to WO number, as if there were a vertical numeric axis, while keeping them grouped horizontally by Croc ID. The result was a plot displaying information about the relationships among all three attributes, which closely resembled the one made by S14 (see Figure 3). Our guess is that if we videotaped individual students as they made their graphs with sticky notes, we would frequently observe this type of gradual revision leading up to their final representations.

Another possible explanation for the superior performance of the Data Card Group has to do with the fact that these students had no prior experience making graphs with sticky-notes. Because of this, they may have felt less constrained in their thinking than did the Traditional Group about what they could or ought to do with the data. In support of this possibility, there is some indication that students in the Traditional Group were stymied by their view of the limited graphing options they considered open to them. Several minutes into the graphing task, we approached three different students in the Traditional Group because they appeared stuck and somewhat anxious. When we asked how they were doing, they responded:

T1: Why can’t you just look at the table? I don’t know how to make a graph with three things [attributes]. Can I ignore one column [of the table]?

T3: Can I just count up the number of singles, doubles and triples?
Res.: You can do whatever you think will help.
T3: Oh good!

T5: It [the graph I’m thinking of making] won’t make sense.

After making these comments, T3 quickly moved on to draw a single-attribute bar chart. T1 and T5 eventually drew graphs that were adaptations of the bar chart but included WO number. But because they had spent approximately 15 minutes thinking before beginning making their graphs, neither completed their graph in the first session.

We should note that the problem here is not only that the students in the Traditional Group felt constrained to use graphs they had learned in school, but that their current repertoire of bar graphs, boxplots, pie charts, etc., where inadequate for the task at hand. Furthermore, having drawn on paper one of these standard displays as a first step, the medium did not lend itself to gradual modifications, as did the medium of the sticky-notes. Only one of the seven students in the Traditional Group who attempted to improve their displays in the second session made a useful modification. The student who was able to improve on his graph did so by creating subdivisions within the bars of his bar chart to show each case. Within each case he wrote the corresponding WO number. Thus, he basically transformed his representation into the type of displays made by the Data Card Group, where each case was clearly represented within the display.

CONCLUSION

The primary purpose of this study was to determine whether the representations made by students using movable elements (sticky-notes in this case) containing all the information of each case would be superior to graphs made by students using the standard pencil-and-paper method. Having indeed shown that the students in the Data Card Group produced more complex, informative representations than the Traditional Group, we then briefly considered various possible explanations for this performance difference. It is important to stress, however, that the current study was designed only to determine where a difference existed, and not to tease out possible explanatory mechanisms.

However, the fact that the students who used a novel medium performed better than students using a practiced one suggests a need to reconsider some of the established practices in introductory instruction in data analysis. While one might question the practicability of using sticky-notes (or similar physical objects), the software *TinkerPlots* offers a medium similar to that of sticky-notes. It is our guess that students using *TinkerPlots* would perform similarly to the Data Card Group, since the operations in *TinkerPlots* are analogs to those used by the Data Card Group.

Among the established educational practices worth reconsidering is that of having students spend many of the early years exploring only data involving single attributes and using simple graphic forms such pie and bar charts. Perhaps even more questionable is the perspective that underlies this assumption — that a major objective of instruction in data analysis is for students to develop a canonical set of graphing techniques. This study, along with others (Konold, 2002), suggests that an unintended outcome of training students in the use of a limited representational tool kit is that it may thwart their native abilities to reason about data and situations involving relationships among multiple attributes.

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