

INTRODUCTION

Tying together the learning opportunities offered by statistics education technologies with students' propensity to use technology in particular ways has implications for pedagogical practice. Research agendas, however, have not included the way in which students interact with the elements of statistical software packages when working within the learning environments afforded by the software. To address the gap, the study reported in this article explored students' use of *TinkerPlots: Dynamic Data Exploration* (Konold & Miller, 2005) in order to determine the strategies students used to access the elements of *TinkerPlots* to construct a variety of graphical representations. It was determined that the students displayed three dominant strategies – *Snatch and Grab*, *Proceed and Falter*, and *Explore and Complete* – within a problem context. The research also suggests that the three strategies have varying levels of productivity in terms of potential learning outcomes and ability to facilitate engagement in further analysis of the data from the graphical representations produced.

1. BACKGROUND

1.1 Statistical software

The introduction of exploratory data analysis (EDA) by Tukey in 1977 opened up the opportunity to work with data in creative and innovative ways. It provided a means of presenting and analysing data without the need for formal statistical calculations and exploited the potential of visual representations to tell the story about the data. Although EDA strategies were developed before personal computers became ubiquitous, Tukey was insightful when he suggested that computer software be developed for EDA. At that time, Tukey collaborated with Velleman and Hoaglin (1981) to develop the programming required to translate the EDA strategies into computer software. This paved the way for the development of innovative software, of which *TinkerPlots: Dynamic Data Exploration* (Konold & Miller, 2005), is an example.

Most commercial statistical packages, educational data analysis tools, web-or computer-based applets, and simulation software can be described as route-type or landscape-type software. Route-type software are designed to fit in a particular learning trajectory (Garfield & Ben-Zvi, 2004). Often they are designed to be introduced in a learning sequence when it is anticipated they will support students' thinking and understanding to evolve within in the context of the learning activities (Behrens, 1997; Ben-Zvi & Friedlander 1997; Simon, 1995). Cobb, McClain & Gravemeijer (2003) employed this strategy when they used three statistical computer minitools (graph applets) to support the development of Year 8 students' understanding of covariation. Cobb et al. designed the minitools to assist students to reorganise their thinking about univariate data to thinking about the relationship between bivariate data. The use of the minitools meant that the students had no choice in the initial construction of the graphical representation and were limited in the way in which they could change the graphs. This strategy maintained the students' focus on the aspects of the graphs that were thought to be most important at the time they were introduced in the learning trajectory.

Landscape software are underpinned by a different philosophical stance than that of route-type software. Although they use many of the same tools, they vary from route-type software because they “provide an open landscape in which teachers and students may freely explore

data” (Garfield & Ben-Zvi, 2004, p. 402). One of the aims of landscape software is to provide a learning environment where students can manipulate elements of graphical representations in order to create graphs that are meaningful to them and assist them to answer questions about the data. By not providing pre-established graph types, landscape software do not constrain students’ choices about which graphical representations are most useful and allow students to take different routes along a learning trajectory. Bakker (2002) warns, however, that the management of multiple learning routes in the one classroom places high demands on the teacher to support potentially very different explorations of the data. He also adds that the nature of landscape software may be overwhelming and distracting for some students.

Some software packages provide a learning environment that may be considered a middle ground between route-type and landscape-type software. “They offer a variety of simultaneous representations that are easily manipulated and modified, as well as simulation of different distributions” (Garfield & Ben-Zvi, 2004, p. 402) but do not offer the freedom of the more sophisticated landscape software as graph types are selected from a set range of graphs and once selected cannot be manipulated or changed. To change an attribute in a scatterplot, for example, a new graph must be constructed. The effective use of this type of software relies on the students knowing which graph type best suits their purposes before creating the graphs and having an understanding of the difference between categorical and continuous data.

The data analysis tool available on the U.K. CensusAtSchool website (<http://www.censusatschool.org.uk/>) is an example of a middle ground between route-type and landscape-type software applet, which is similar to commercial software packages. As can be seen in Figure 1, a selection of graphs to choose from is provided. The list on the left indicates the variables in the data set. The continuous attributes are coded yellow, whereas the categorical data are coded pink. Each graph type has a colour coded bar to indicate the type of variable to add to each graph type. To create a graph, one or more of the variables are dragged onto the graph type chosen and the software generates the completed graph. The colour coding of attributes is useful as it provides a hint for selecting the graph type and which attributes to use for that graph type. The software, however, is restrictive as it only generates a particular graph at a time and does not allow the user to transition directly from one graph type to another. If a different graph type is required the user must create a new graph. The U.K. CensusAtSchool graph selection is superior to other similar commercial statistical software packages as it will not generate 3-D plots and starplots unless three continuous attributes are selected.

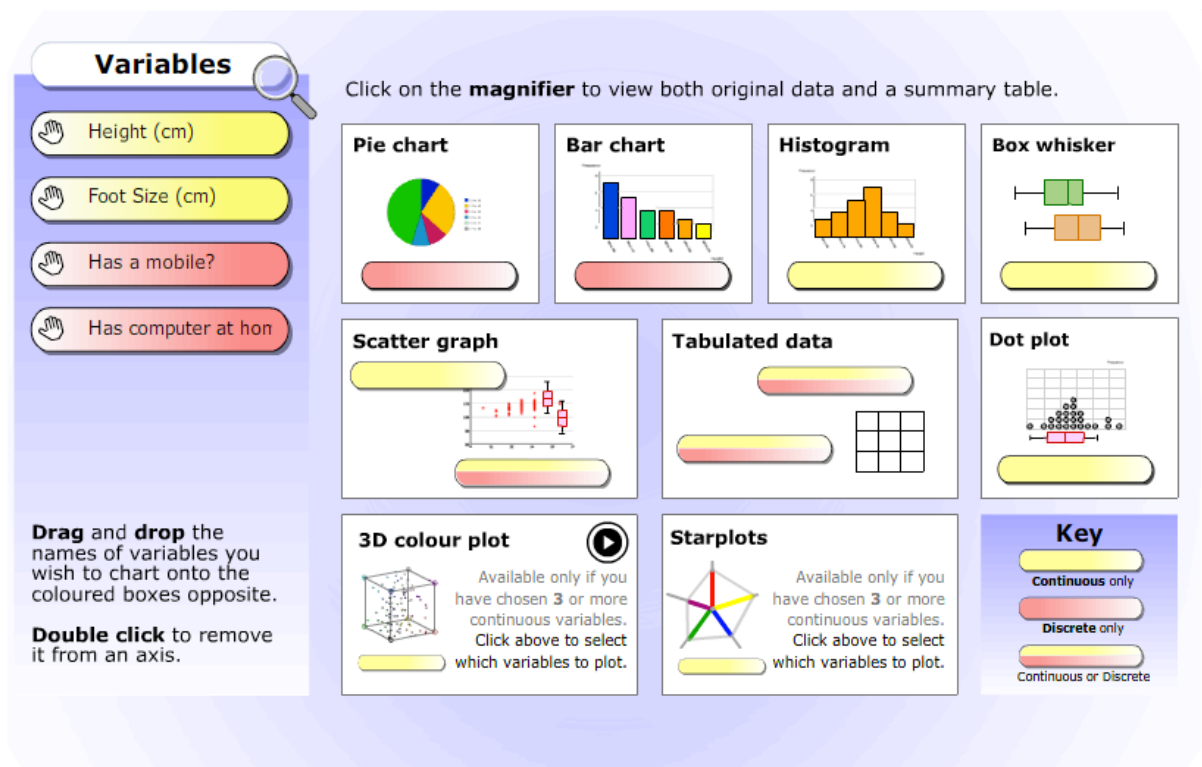


Figure 1. U.K. CensusAtSchool data analysis tool interface.

1.2 The case of *TinkerPlots*

The software used in the study reported in this article, *TinkerPlots*, is considered a landscape-type software program. It was designed specifically as a construction set to enable middle school students to build intuitive ideas about distributions and explore the potential of different graphical representations to answer questions about data. The fundamental underpinning ideas that guided the development process were that *TinkerPlots* should build on what students know and are inclined to do when organising data displays and reasoning about data, and that educational tools should address the way in which students learn in those environments (Konold, 2007).

In the development of *TinkerPlots*, Konold and Miller (2005) took heed of Biehler (1997), who suggested that educational software tools should become more sophisticated as the user gains more expertise, in much the same way as complexity is incorporated into computer games. He also suggested that software include elements that could be drawn on piece by piece when needed. Konold and Miller built *TinkerPlots* around a conceptual structure that allowed “students [to] 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” (Harradine & Konold, 2006, p. 1). Konold (2007, p. 279) states, “It is this ability to combine operators in *TinkerPlots* that makes it complex, and powerful.” The many operators and elements that can be combined collectively but also accessed individually to build graphical representations, distinguishes *TinkerPlots* from professional graphing tools, such as MSEXcel.

An example of a typical scatterplot created in *TinkerPlots* is shown in Figure 2. The triangular icons on the vertical and horizontal axes indicate the mean for the corresponding attribute. The data are highlighted for the attribute height. Figure 3 displays a scatterplot showing the relationship between two attributes with the vertical scale divided into bins. In

this graph the mean of the attribute on the horizontal axis is displayed for each bin width. The relationship between height and weight can be described by looking at the trend displayed in the mean of the weight in each of the bins as the height increases.

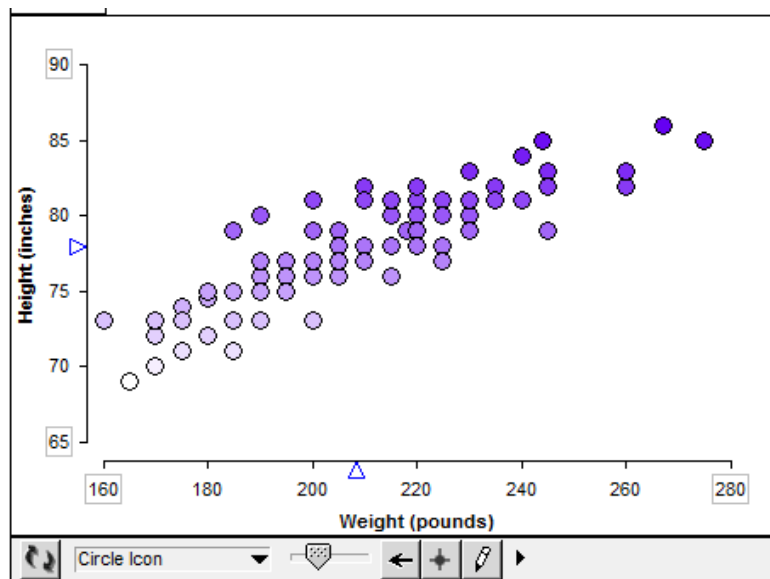


Figure 2. Scatterplot with a continuous scale on each axis that shows the relationship between weight and height of basketball players.

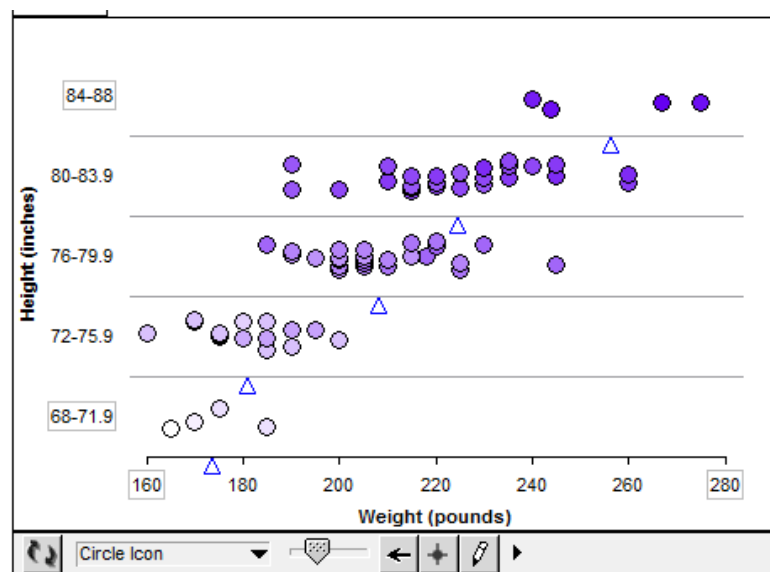


Figure 3. Scatterplot with the vertical scale divided into bins showing the relationship between height and weight of basketball players with the mean added to the graph.

As well as the basic functions of stack, order, and separate, Konold and Miller (2005) included elements such as the reference line, dividers, measures of centre, and the hat plot. The hat plot is a unique summary tool that resembles a hat and is made up of two main components – the crown and the brim. When first initialised, the crown of the hat is a rectangle that shows the middle 50% of the data and the brim of the hat is a line that extends across the full range of the data set. The sections of the brim of the hat on either of the crown represent 25% of the data respectively. An example of a hat plot with vertical reference lines added is in Figure 4. The data in the graph are separated according to gender on the vertical axis. Also in the figure are three data points to the right of the graph. These data points

indicate that there are cases in the data set with no values recorded for the attribute `active_rate`. The text to the right of the graph was added by the student who created the graph. As well as being able to insert text boxes it is also possible to insert images into *TinkerPlots*. These additional features allow students to write reports about the data in the same file in which they analyse the data. There is also the potential for teachers to set up data and questions to be answered in the form of worksheets within *TinkerPlots*.

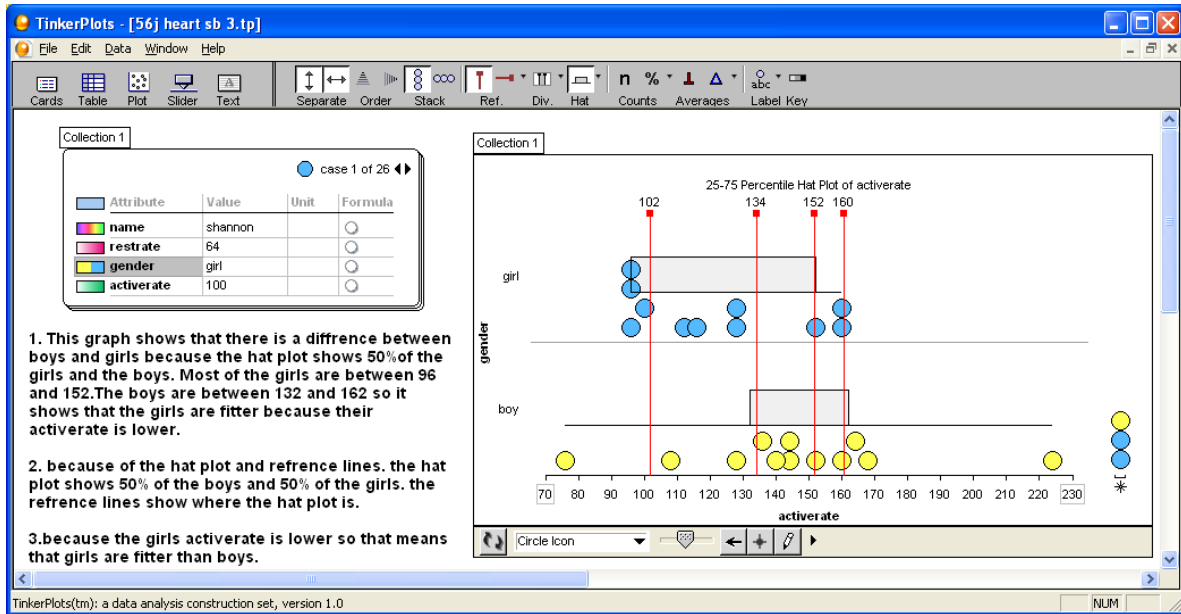


Figure 4. Hat plot created in *TinkerPlots* with data stacked and vertical reference lines added. Reproduced from Watson & Donne (2009).

TinkerPlots has been utilised successfully in a variety of contexts and research studies. For example, Ben-Zvi (2006) and Fitzallen and Watson (2010, 2011) used *TinkerPlots* to scaffold and extend students' statistical reasoning when developing an understanding of informal inference and argumentation; Watson and Neal (2012) made explicit the links between classroom practices with *TinkerPlots* and the curriculum; Watson and Donne (2009) demonstrated the utility *TinkerPlots* as a research tool when they investigated Year 5-and-6 students' understanding of informal inference; and Watson, Beswick, and Brown (2012) as well as Watson, Skalicky, Fitzallen, and Wright (2009) demonstrated how *TinkerPlots* was used to support teachers' knowledge of statistical concepts in professional learning.

To date, very little research has explored if students engage with *TinkerPlots* in the way Konold (2007) intended. Lehrer, Kim, and Konold (2010) did, however, conduct a study that explored Year 6 students' use of *TinkerPlots* to develop measures of variability. The two case studies reported suggest that the students' spontaneous use of the elements of *TinkerPlots* together with interaction with the rest of the class, teacher, and researchers supported a transition in thinking about the precision of measurements made. The authors report that

Although some of the use of *TinkerPlots* by these students could be predicted from the nature of the functions and displays that the software employs, much of what students did was contingent on results of their explorations and emerged as they noticed something new resulting from these explorations. It was noteworthy that the software supported very different trajectories of learning. (p. 6)

This suggests that the outcomes of students' interaction with *TinkerPlots* may vary and investigating the characteristics of the way in which students interact with the software is worthy of further investigation.

1.3 Model of learning in EDA software environments

In order to investigate how students interacted with *TinkerPlots* it was necessary to develop a framework for analysing the way in which the students worked within the learning environment *TinkerPlots* offered as well as how the students used the features of *TinkerPlots* to create and interpret graphical representations. Models developed by Friel, Curcio, and Bright (2001), Moritz (2004), Pfannkuch and Wild (2004), and Shaughnessy (2007) in relation to graphing and graph sense-making, and Kosslyn (1989) in relation to the characteristics of graphs, were reviewed to provide an extensive view of the development of graphing and graph sense-making. Common to all of these models was a lack of acknowledgement of the influence of technological learning environments on the graph creation and interpretation processes undertaken by students. To address the short fall, the work of Alessi and Trollip (2001) in relation to the features of technological learning environments was also considered. Aspects of each of the frameworks most relevant to the learning environment offered by *TinkerPlots* were used to develop a new framework, Model of Learning in EDA Graphing Environments (Table 1). This framework incorporates the key behaviours of graph creation and interpretation (middle column of Table 1) extracted from each of the models from the literature into four interconnected dimensions: Being creative with data, Understanding data, Thinking about data, and Generic knowledge. The right-hand column of the table details the contributors from the literature that informed the development of the dimensions of the model. Also noted are the sections used from each of the particular frameworks. The development of the Model of Learning was first reported in 2006 (Fitzallen) and applied in Fitzallen and Brown (2006, 2007) and in Fitzallen (2008, 2012). Although the Model of Learning does not incorporate all the cognitive aspects and behaviours associated with statistical thinking and reasoning, it is useful because the four dimensions provide focus points for analysing the strategies students use when interacting with *TinkerPlots*.

Table 1

Dimensions, Key Behaviours of the Model of Learning in EDA Graphing Environments and the Contributors to each of the Dimensions

Dimensions	Key Behaviours	Contributors
Generic knowledge	Speaking the language of data and graphs.	Friel et al., (2001), <i>Reading the data</i> Moritz (2004), <i>Verbal graph interpretation</i> Kosslyn (1989), <i>Constituent parts of graphs</i>
	Understanding how to use the features of software and technology environments.	Alessi & Trollip (2001), <i>Navigating the interface, Accessing the features, Supplementary materials</i>
	Recognising the characteristics of data and graphs.	Friel et al., (2001), <i>Reading the data</i> Moritz (2004), <i>Numerical and verbal graph interpretation</i>
Being creative with data	Reducing data to graphical representations. Summarising data.	Pfannkuch & Wild (2004), <i>Transnumeration</i> Pfannkuch & Wild (2004), <i>Transnumeration</i>
	Constructing different forms of graphs.	Pfannkuch & Wild (2004), <i>Transnumeration</i> Moritz (2004), <i>Graph production</i>
	Describing data from graphs.	Moritz (2004), <i>Verbal graph interpretation</i>
Understanding data	Making sense of data and graphs.	Friel et al., (2001), <i>Reading within the data</i>
	Understanding the relationship among tables, graphs, and data.	Friel et al., (2001), <i>Reading within the data</i>
	Identifying the messages from the data.	Pfannkuch & Wild (2004), <i>Transnumeration</i>
	Answering questions about the data.	Friel et al., (2001), <i>Reading beyond the data</i>
	Recognising appropriate use of different forms of graphs.	Pfannkuch & Wild (2004), <i>Transnumeration</i> Friel et al., (2001), <i>Reading beyond the data</i>
Thinking about data	Asking questions about the data.	Moritz (2004), <i>Verbal graph interpretation</i>
	Recognising the limitations of the data.	Shaughnessy (2007), <i>Reading behind the data</i>
	Interpreting data.	Friel et al., (2001), <i>Reading beyond the data</i>
	Making causal inferences based on the data.	Shaughnessy (2007), <i>Reading behind the data</i> Moritz (2004), <i>Causal inference</i>
	Looking for possible causes of variation.	Shaughnessy (2007), <i>Reading behind the data</i>
	Looking for relationships among attributes in the data.	Shaughnessy (2007), <i>Reading behind the data</i>

2. THE STUDY

The aim of this article is to identify the students' strategies when interacting with *TinkerPlots*. In order to do so it was necessary to set up an exploratory study. A teaching experiment (Steffe, 1991) was designed to allow the researcher to act as the teacher in the study (Steffe & Thompson, 2000). This approach facilitated close scrutiny of the students' actions and conversations with the teacher/researcher as they worked individually at the computer. This article focuses on answering the research question:

What strategies do students use when they interact with the exploratory data analysis software *TinkerPlots*?

The larger study from which this report is taken focused on the students' development of understanding of covariation (see Fitzallen, 2012).

2.1 Method

The participants in the study were 12 Year 5-and-6 students (11-12 years old). The sample was drawn from a primary school involved in an Australian Research Council Linkage Project, *Providing the Mathematical Foundation for an Innovative Australia within Reform-based Learning Environments* (MARBLE) (Watson et al., 2012), which was a professional learning program for teachers in rural and regional schools. The students were selected by their teachers to participate in the study.

Over a period of six weeks the students worked in pairs through a sequence of learning experiences that introduced them to the elements of *TinkerPlots* for graph creation and data analysis as well as the fundamentals of graph interpretation. At the end of the learning sequence the students completed data analysis activities and answered questions about the data analysis process. This was undertaken as they worked individually with *TinkerPlots* during a 45 minute Student Interview session with the teacher/researcher. The data for the study were collected during the session by on-screen capture video *Captivate* (Adobe, 2007), as the students worked at the computer. *Captivate* generated both audio and video data. The audio data from the *Captivate* digital files provided evidence of what the students said and the on-screen video data provided evidence of what the students did.

The data set used in the Student Interview activity was generated from the Australian CensusAtSchools data base (www.abs.gov.au/censusatschool). This provided a random sample of 200 Year 5-and-6 students from across Australia. The attributes in the data set were: gender, foot length, height, and belly button height. The data set was imported into a *TinkerPlots* file, which was then used by the students to complete data analysis activities and answer questions about the data during the Student Interview. The teacher/researcher's role was to support and guide the students through the activity and to ask the students questions in order to give them the opportunity to clarify statements and elaborate on responses to questions. The Student Interview questions are noted in Figure 5.

TinkerPlots - [Interview 7 Fairview with Questions.tp]

File Edit Data Window Help

Cards Table Plot Slider Text Separate Order Stack Ref. Div. Hat Counts Averages Label Key

Collection 1

Attribute	Value	Unit
Student_No	S1	
Sex	Female	
Height	147	cm
RighFoot	20	cm
BillyButn	86	cm
<new attribute>		

case 1 of 200

Collection 1

Student Interview Protocol

Data about 200 Year 5/6 students in Australia

Attribute Description

Student_No.: student ID code
Sex: gender of student
Height: height of student in centimetres
RighFoot: length of student right foot in centimetres
BillyButn: height of student's belly button in centimetres measured from the ground

Guiding Conversation - Setting the scene and reminding about other sessions

Explain data set has 200 cases of Year 5/6 students extracted from the CensusAtSchools database.

What information is included in the data set?

What questions did you answer with the data sets in the other sessions?

What features of *TinkerPlots* did you use in other sessions?

Questions:

What interesting things can you find out about this data set?

Create some graphs that show the relationship between two attributes.

Explain to me what you are doing as you construct the graphs.

What do the graphs tell you about the group of students?

Is there another way you can organise the information that might be useful?

Are there any features of *TinkerPlots* that might help you make sense of the data?

What does the graph tell you about the relationship between the two attributes?

Compare all of the graphs you have created. Which graph shows the strongest relationship between two attributes?

What characteristics of the graphs helped you make your decision?

TinkerPlots(tm): a data analysis construction set, version 1.0 NUM

Figure 5. *TinkerPlots* file with questions used in the Student Interview sessions.

2.2 Data analysis

The audio data from the on-screen videos generated by *Captivate* (Adobe, 2007) were transcribed verbatim. The audio transcripts were then synchronised with the on-screen capture video data and descriptions of the students' actions at the computer were added to the audio transcripts. The audio transcripts together with the descriptions of the students' actions underwent a thematic analysis. Thematic analysis, as described by Miles and Huberman (1994), was used to explore the audio transcripts further to determine the students' strategies when interacting with *TinkerPlots*. In thematic analysis the aim is to identify a limited

number of themes that adequately reflect the essence of the data. Miles and Huberman (1994) suggest that researchers start with general themes and sub-themes derived from reading the literature. The clustering of the themes and sub-themes forms the basis for drawing and verifying conclusions.

The themes used to code the data from the Student Interviews were derived from the Model of Learning in EDA Graphing Environments (Table 1). The dimensions of the Model of Learning – Generic knowledge, Being creative with data, Understanding data, and Thinking about data – served as themes for the coding process and the key behaviours in the dimensions of the Model of Learning served as subthemes for exploring the data further. The dimensions were appropriate codes for the transcribed data as they were derived from the literature, as suggested by Miles and Huberman (1994).

The data coding process involved line-by-line scrutiny of the combined audio and video transcripts for each of the participants. Each line was coded according to the relevant key behaviours from the Model of Learning. Following the coding process the data were grouped according to the four dimensions of the Model of Learning. The grouped data were then analysed to determine the dominant strategies each of the students used when interacting with *TinkerPlots*. As the aim of this article is to identify the strategies students used, qualitative data only are reported.

3. THE RESULTS

The strategies that dominated/exemplified the ways in which the students engaged with *TinkerPlots* in the data analysis process were: *Snatch and Grab*, *Proceed and Falter*, and *Explore and Complete*. A list of the students according to each of the strategies adopted is in Table 2. In this section vignettes are presented to describe the approach taken by each of the students in order to illustrate the characteristics of each of the strategies.

Table 2.
Students and Interaction Strategy Adopted When Using TinkerPlots

Strategy	Snatch and Grab	Proceed and Falter	Explore and Complete
Students	Natalie, Natasha, Kimberley, Johnty	Shaun, Blaire, Rory, Jessica, Jake	James, William, Mitchell

3.1 Snatch and Grab

The *Snatch and Grab* strategy was used by students who had incomplete knowledge about the potential of *TinkerPlots* to support data analysis activities. They were not always self-directed in their selection of graph types and required prompts and suggestions from the teacher to extend their exploration of the data beyond the basic graph construction phase. These students tried to take advantage of *TinkerPlots* by adding multiple elements, such as the hat plot and the mean, to the graphs but made little sense of how the elements contributed to a better understanding of what the graphs showed. The students often accessed the elements in a random manner. They appeared to access the elements they were familiar with in the hope the elements helped answer the questions. On occasions they were successful but more often the students could not see how the additional elements contributed to the ability to answer the questions about the data.

Although Natalie's responses and descriptions were not very sophisticated, she demonstrated she had established a basic understanding of the utility and purpose of graphs. She was open to exploring the application of *TinkerPlots* and had a positive attitude about the software and its potential. As she worked she adopted a "let's see what happens" attitude and accessed multiple elements of *TinkerPlots* to find a representation that assisted her to answer the questions about the data. It was evident that she drew on her previous experiences to interpret graphs but had difficulty as her knowledge and understanding was limited. Natalie knew many pieces of different information about graphs and graphing but she had not made significant connections between these pieces of information. This constrained her thinking, restricted her examination of graphs, and stymied her explanations as she grappled to put all her ideas together. Like other students, Natalie's interpretation of graphs focused on specific data values and did not extend to consideration of relational characteristics.

Although not always self-directed in the construction of graphs, Natasha showed that she had an established knowledge of a variety of graph types and how to use them to extract specific information. Her graph interpretation skills, however, were undeveloped. Like a number of other students, Natasha had gained knowledge about graphs and data but had not made meaningful connections between what she knew and how to use it effectively. Sometimes her interpretations were incomplete but they were sufficient to establish that she had an emerging understanding of how graphs could be used to interpret data and tell a story. Natasha accessed many of the elements of *TinkerPlots* as she created a variety of graphs but she often sought reassurance from the teacher that her choice was going to be productive. It became evident that Natasha based her selection of elements on her knowledge of what was available rather than being a purposeful choice because she understood how the feature was going to facilitate the data interpretations.

Kimberley wanted the physical appearance of the graphs to fit a preconceived idea. She liked the data points to be separated and did not feel comfortable when they were all bunched together. When the graphs had clusters of data that were bunched, she had trouble "reading" the graphs. This prevented her from looking at aggregates of data to tell a story and caused her to focus on individual data points on the fringe of clusters. Although Kimberley was hampered by what she perceived as lack of clarity, she was not hampered by expecting a certain type of graph and was able to work flexibly within the constraints she imposed. Within the *TinkerPlots* environment she created different types of graphs and did not follow any particular routine when constructing the graphs. Kimberley used the elements of *TinkerPlots* in much the same way with all the graphs she constructed. The tinkering she did by changing the size of icons, plot windows, and scales of axes, as well as inserting hat plots, the count, the mean, and reference lines, was her attempt to get the graphs to a point where they answered the questions she was exploring. Kimberley took advantage of the tools she had at her disposal within the *TinkerPlots* environment to help her think through what the graphs offered. She identified readily whether they were useful or not but tried them all. There were times, when this way of working was not very productive but at other times proved to be helpful.

Johnty required reminders about how to create graphs and access the elements of *TinkerPlots*. As the session progressed he became more competent but was inconsistent in the way he worked. He was also inconsistent in the way he interpreted graphs. Sometimes his responses to questions only involved stating the specific value of data points. Other times, he offered responses that showed the complexity of his thinking when interpreting graphs. Johnty showed that he understood the characteristics of graphs and used the structure of graphs to

convey his understanding. He also showed he had the potential to go beyond the use of individual characteristics to describe the data to interpreting the data from a global perspective. Like Kimberley, Johnty fiddled constantly with the graphs by changing the appearance of the size of the plot window and the data icons, as well as accessing all the available elements of *TinkerPlots* without purpose and often inappropriately. This was evident when he tried to add hat plots to a graph without a continuous scale and tried to stack the data in a scatterplot.

3.2 Proceed and Falter

The students who used the *Proceed and Falter* strategy used *TinkerPlots* purposefully as a construction tool. They were purposeful in the way they went about creating graphs and approached the tasks given with confidence. These students understood which graph type could be useful to answer the question asked but often did not follow through with responses that indicated they understood why the representations were useful. At this stage, the students benefited from suggestions from the teacher to move on and explore the data further. Often these students relied on their prior learning of graphing and statistical concepts to answer questions. This constrained the students' thinking and prohibited them from being open to the story the data representations had to tell.

Jake was not very adventurous and did not experiment with the options *TinkerPlots* made available. His choices of graph types and elements to apply were based on what he wanted to see happen. When a representation did not appear as expected, he became hesitant and did not experiment with the features of *TinkerPlots* to change the graphical representations beyond the initial graph created. As a consequence, Jake treated the graphs he constructed like graphs printed on paper – static and fixed. Because his interpretation of graphs was influenced by his established expectations, he did not instigate changes to his graphs once completed to his satisfaction.

Blaire was another student who was constrained by established ideas but it was not the look of the graphs that restricted her thinking. Blaire's focus was on using the mean to make sense of the graphs. When referring to the mean she used the term "average" but often her application of the mean was inappropriate. As she described the average from a scatterplot, the language she used described the mode not the mean average. On another occasion she described the mean as being in the middle of a cluster of data. In some instances, she used the numerical value of the mean generated by *TinkerPlots* to compare groups. In these cases she used the mean as a single value and did not demonstrate that she understood the mean was representative of the whole group of data. When asked to explain what the "average" meant, Blaire read the data value from the graph and did not expand further.

Rory was another student who was confident enough to create a variety of graphs without assistance but often did not go further when asked to discuss and describe what the graphs revealed about the data. Rory often lacked initiative, which may be attributed to his lack of understanding of data, in general, and how they were represented in *TinkerPlots*, more specifically. He demonstrated that he knew how to use *TinkerPlots* but chose not to use it in the same way other students had done to move past an initial plot and explore further possibilities in the data. Rory was not very adventurous and did not use the elements of *TinkerPlots* to advantage. He accessed the features but did not always acknowledge that the features added something to his understanding of the graphs. His understanding of how to use *TinkerPlots* to facilitate the interpretation of data was limited.

Jessica was knowledgeable about *TinkerPlots* and worked confidently and instinctively with the software to create graphs. Jessica knew what graph type would fulfil what she was asked to do but it was not evident that she knew how to use the graphs effectively to answer questions. This was also the case when she used the hat plot and the mean. Jessica knew these representations were useful but could not articulate why. As a fall-back position, Jessica focused on individual data points in graphs and her intuitive knowledge of the context to make informal inferences about the data. When not focussing on individual values, she focused on the centre of the data. The elements of *TinkerPlots*, such as the mean and the drawing tool, helped Jessica by giving her a point of focus to stimulate her thinking.

Although Shaun experienced lapses of memory about how to use *TinkerPlots* and the language needed to explain the graphs and their characteristics, he was still able to connect with the representations constructed with the software. He did not, however, always understand what some of the elements contributed to the interpretation of the data and his explanations offered few insights into his thinking about the data and the way in which he used the elements of *TinkerPlots* to make his decisions. Shaun recognised the changes to the graphs when deleting outliers, speculated about the variation in the data when determining a relationship between attributes, and anticipated where the crown of a hat plot would sit on a graph. This showed that he actively used the representations offered in *TinkerPlots* to interpret the data but there were occasions when his interpretations were flawed and hence revealed an incomplete understanding of some representations.

3.3 Explore and Complete

The students who used the *Explore and Complete* strategy used *TinkerPlots* effectively to support the interpretation of graphs. This approach, as the name implies, was characterised by a sense of exploration thus allowing the data to take centre stage and *TinkerPlots* to play a supporting role. These students did not pre-empt what the graphs would look like or predict the story the graphs had to tell before they were constructed. As a result, the responses to questions and the descriptions of graphs conveyed that the intuitions developed about graphing and data analysis were shaped by the data representations. Explanations about the data were unhampered by fixed ideas and preconceptions and often decisions were made quickly about what a graph showed and those decisions were in response to the representations *TinkerPlots* offered.

William was unusual in that he was the only student who chose not to use a continuous scale to determine if there was a relationship between two numerical attributes. When he created the graphs he dragged the axes enough to extend the number of bins but not enough to create a continuous scale. He then added the mean but was unsure how to interpret the resulting representation. William was not deterred by this as he was able to interpret the graphs appropriately by using his understanding of the spread of the data and the relational nature of scatterplots that display covariation to make conclusions about the data. Although William displayed hesitation when confronted with representations he did not fully understand, it did not constrain his thinking and he was able to explore the data further using other representations.

James worked confidently and was able to create a variety of graphs without assistance. Once he created the graphs he did not refer back to the case cards and focused his attention on the graphs to determine values of data points. James did not need the reassurance of reading

values from the case cards, the mean, and reference lines as Kimberley and Blaire had done. Although he did apply these elements to the graphs, he was much more confident and did not need the values generated by the elements to confirm his thinking. James' interpretation of graphs focused on the distribution of the data. His decisions were influenced by the physical structure of the graphs and the position of the data points within the plot window. James was very purposeful in the way he accessed the elements of *TinkerPlots* and only made changes to graphs, such as adding a hat plot, when he wanted to know what a particular feature had to say about the data. His actions were exploratory in nature but were deliberate and not based on a trial-and-error strategy adopted by many of the other students.

Mitchell explored the story the data had to tell by moving back and forth between looking at clusters of data and individual values. He was able to integrate these two characteristics of graphs into his decision making process. This enabled him to make decisions about graphs from a general perspective and then use specific values to justify his decisions and identify variation. His interpretations of the data were based on the position of data points in a graph rather than their specific values. The connections Mitchell made to the context of the data were directly related to his interpretation of the graphs and were not influenced by his knowledge of and previous experience with the context. Unlike James, Mitchell did adopt a trial-and-error strategy when accessing the different elements of *TinkerPlots* but knew immediately if the changes instigated were useful.

4. DISCUSSION OF STUDENT STRATEGIES WHEN INTERACTING WITH *TINKERPLOTS*

The three strategies adopted by the students – *Snatch and Grab*, *Proceed and Falter*, and *Explore and Complete* – show the different ways in which the students worked within the *TinkerPlots* learning environment and reveal the students' propensity to exploit the affordance of the software in different ways. The students who employed the *Explore and Complete* strategy had a comprehensive way of working with data. They successfully integrated their knowledge of graph creation and graph interpretation when describing and analysing the data. Most of the time, their thinking and actions moved back and forth between graph creation and graph interpretation as they made sense of the data.

The students who employed the *Proceed and Falter* strategy put their initial efforts into creating graphs and then stopped and interpreted the data as a separate activity. At times, focused questions for the teacher/researcher were necessary for some of the students to transition successfully from the creation mode to the interpretation mode. The students who employed the *Snatch and Grab* strategy, often worked aimlessly when interpreting the data. They did this by repeatedly accessing multiple elements of *TinkerPlots* without considering if the particular elements would be useful or not. Like the other students, the students who used the *Snatch and Grab* strategy were competent at using *TinkerPlots* to create graphs and relied on the elements of *TinkerPlots* to provide the inspiration needed to think about the data. As these students did not take time to think about the changes they made, many of the elements accessed were redundant and not helpful. Also, little advantage was taken of the affordances of the elements that may have been useful.

Students who used the *Explore and Complete* strategy make strong connections between the graphical representations and the meaning they embody. When this occurs, the teacher can focus attention on what the data mean and inferences that can be made from the data. When

students use the *Proceed and Falter* strategy, teacher intervention may need to focus attention on how the graphical representations answer the question being explored before attention is given to thinking further about the data. When students use the *Snatch and Grab* strategy, teacher intervention may need to focus on both the graphical representation and the question being explored to ensure the students develop an understanding of the alignment necessary between the graphical representations constructed and the way in which they help to answer the question.

5. IMPLICATIONS FOR THE CHOICE OF SOFTWARE

Effective and productive learning will not occur by just giving students access to statistical software. The teacher must play an active role in establishing and supporting the development of student thinking and reasoning (Behrens, 1997; Ben-Zvi & Friedlander, 1997; Cobb et al., 2003). As students' statistical understanding and knowledge of graphs becomes more sophisticated "the teacher's role changes from active instructor to fellow investigator" (Ben Zvi & Friedlander, 1997, p. 54). Having an understanding of how students use interactive software would inform teachers about when to and in what ways to intervene in the learning process.

The decisions made every day about what resources to use and which activities are best suited to support students' learning needs are based on, among other things, the teachers' pedagogical content knowledge. The choice of software used in classrooms should also be informed from a pedagogical perspective and be based on the ability of the software to construct the graphical representations required as well as the ability to support the students' thinking and reasoning when analysing data. Bakker (2002) suggests:

The choice of one or the other program also has to do with the aim. If the aim is to guide a class as a whole towards understanding specific statistical notions and graph types, then a route-type tool might prove more suitable. When aiming at genuine data analysis with multivariate data sets from the start, a tool like *TinkerPlots* is more appropriate. (p. 5)

The three dominant strategies used by the students suggest that the idea of choosing different software for particular learners may also be beneficial. The use of *TinkerPlots*, which is landscape-type software provided students with the chance to work freely within the software learning environment to construct graphs that were meaningful to them. This type of software appeared to be most suited to the students who adopted the *Explore and Complete* strategy. For the students who adopted the *Proceed and Falter* strategy, combination route-and landscape-type software may be more suitable. In addition, the students who adopted the *Snatch and Grab* strategy may be better served by route-type software that has the potential to focus attention on particular statistical concepts and notions without the distraction of additional software elements.

6. RECOMMENDATIONS FOR FUTURE RESEARCH

Because this was an exploratory study and the aim of this article was to identify the dominant strategies students' used, no quantitative data were analysed for this report. Anecdotal evidence gathered from observations made during the Student Interviews and viewing of the video recordings established that the individual students do not always use the same strategy but did favour a particular strategy. This suggests there is a need to explore further the

underlying structure of the strategies identified to determine if the strategies are discrete or lie on a continuum of approaches. Also identifying what prompts students to transition from one strategy to another would be useful. Further research is also required to determine if students' development of statistical thinking and reasoning is influenced by particular aspects of statistical software and if the way in which students interact with software is hierarchal. It would also be interesting to determine if the dominant strategy used by students was a precursor to the way in which students make sense of and develop an understanding of statistical ideas and concepts.

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