Developing Statistical Thinking Using Experiential Learning While Learning to Teach Secondary School Statistics

Margaret Marshman Peter K. Dunn
University of the Sunshine Coast

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Secondary preservice teachers' experiences in their discipline studies may lead to preconceived ideas about appropriate pedagogies without understanding how to implement them. In our experience, many students claimed to be using an experiential learning pedagogy in their lesson planning when they were teaching directly from the textbook. Experiential learning is the underlying pedagogy used in Outdoor and Environmental Studies. It occurs through active engagement in an experience and subsequent reflection on the experience. In this article we present two teaching activities—Random and non-random sampling, and An appropriate measure of centre (mean or median)—to illustrate how the experiential learning cycle could be used to develop statistical thinking as part of a course learning how to teach secondary mathematics. In interviews, secondary mathematics preservice teachers described how they planned to address students' misconceptions and develop students' statistical thinking in the future. The findings suggest that engaging in contextually specific abstract conceptualisation can develop statistical thinking.

Keywords • mathematics teacher education • statistical thinking • preservice teachers • experiential learning • sampling • measures of average

Introduction

Within secondary initial teacher education, preservice teachers (PSTs) have often completed many of their discipline studies before engaging with the corresponding curriculum and pedagogy courses. Therefore, PSTs may have preconceived notions of appropriate pedagogies gleaned from their learning experiences in their discipline. In our own experience, many students claimed to be using an experiential learning pedagogy in their lesson planning when their lesson plan was sourced from a textbook. Being concerned about how PSTs were interpreting experiential learning we investigated how statistics could be taught experientially as part of a teaching secondary mathematics course.

Snee (1993) claimed that statistics education that focussed on knowledge and skills did not work, arguing that statistical education needed to focus on:

> … how people use statistical thinking and methods to learn, solve problems, and improve processes. Learning from your experiences, by using statistical thinking in real life situations, is an effective way to create value for a subject and build knowledge and skills. (Snee, 1993, p. 149)

In Australian schools, statistics is usually taught within the subject of mathematics by teachers of mathematics, but statistics is often considered different from mathematics (Franklin et al., 2007). This is reflected in the *New Zealand Mathematics and Statistics* curriculum, which states:

> Mathematics is the exploration and use of patterns and relationships in quantities, space, and time. Statistics is the exploration and use of patterns and relationships in data. These two disciplines are related but different ways of thinking and of solving problems. Both equip students with effective means for investigating, interpreting, explaining, and making sense of the world in which they live. (Ministry of Education, para 1, 2014)

Whilst mathematics involves deterministic thinking and develops theorems and proofs, statistics is probabilistic and answers questions within contexts where variation and uncertainty exist (Dunn & Marshman, 2020); Gattuso & Ottaviani, 2011; Franklin et al., 2007). Gattuso and Ottaviani (2011) explained, "While mathematics promotes abstraction, statistics insists on interpretation in context" (p. 126). That is, statistics provides decision-making tools in the presence of uncertainty within a context. Statistical thinking considers "the omnipresence of variability … because data are not just numbers, they are numbers in context" (Cobb & Moore, 1997, p. 801).

Experiential learning is a "learning cycle or spiral where the learner "touches all the bases"—experiencing, reflecting, thinking, and acting—in a recursive process that is responsive to the learning situation and what is being learned" (Kolb & Kolb, 2005, p. 194). Within experiential learning, the activities and learning environment actively engage students in interpreting and understanding new information, transforming their knowledge (Ambrose et al., 2010). Using this empirical article, we report on a study of secondary mathematics PSTs describing how experiential learning helped them to develop understanding of the importance of context and the need to consider variation in statistical thinking. For example, when discussing whether mean or median was the most appropriate measure for river height, PSTs identified knowing the purpose of the data—the question to be answered by the data—influenced the choice of measure of central tendency and noted information about the variation in the data was lost with the data reduction.

Literature Review

Statistical Thinking

Scheaffer (2003) explained that "data analysis and statistical thinking … develop knowledge, beliefs, dispositions, habits of mind, communication capabilities and problem-solving skills that people need to engage effectively in quantitative situations arising in life and work" (pp. 146–147). Context is important for statistical thinking and manipulating data by reduction (Kuntze et al., 2017) and dealing with statistical variation (Watson & Callingham, 2003). When manipulating data by reduction, statistical thinking includes being "aware that by doing this, information is usually lost, and that statistical indicators or representations of data might not reflect all important dealing with statistical variation of the original data set" (Kuntze et al., 2017, p. 925). Statistical thinking also includes considering that "not all variation in data are meaningful" (Kuntze et al., 2017, p. 925).

Cobb (1992) identified four key components for statistical thinking. First, students need to use data to make personal decisions and consider consequences when evidence is not used to support decisions. Second, students need to understand that formulating problems and collecting quality data to answer good questions was time-consuming and difficult. Third, students need to recognise "that variability is ubiquitous. … It must be experienced," and finally, they must embrace the "quantification and explanation of variability", by considering: "(a) randomness and distributions, (b) patterns and deviations (fit and residual), (c) mathematical models for patterns, and (d) model-data dialogue (diagnostics)" (p. 331). Garfield et al. (2015) recommended that the development of statistical thinking should happen in a safe environment where students can make mistakes and express partial understandings.

PSTs often struggle with understanding variability in data and selecting appropriate measures of centre (Browning et al., 2014; Nguyen et al., 2023) and some PSTs struggle to plan statistical investigations, viewing them as a sequence of techniques rather than a comprehensive framework for understanding the world (Santos & Ponte, 2014). However, statistical investigation projects are effective in enhancing PSTs' statistical knowledge and thinking skills (Suh et al., 2020; Zapata-Cardona & Martínez-Castro, 2021) and lesson study improves PSTs informal inferential reasoning and statistical and pedagogical knowledge (Leavy, 2010). Hence, teacher education programs should focus on developing statistical knowledge and thinking for teaching, including understanding variability in data, and using technology-enhanced tasks (Browning et al., 2014).

Teaching and Learning Statistics

The updated *Guidelines for Assessment and Instruction in Statistics Education (GAISE)* (Carver et al., 2016) highlights the importance of teaching statistical thinking through an investigative process of problem-solving and decision-making. Students need opportunities to "think critically about statistical issues and recognize the need for data, the importance of data production, the omnipresence of variability, and the quantification and explanation of variability" (Carver et al., 2016, p. 12). Rather than presenting students with the definitions, formulas, and procedures for calculating statistical terms, students need opportunities to experience "seeing connections among statistical ideas and recognizing that most statistical questions can be solved with a variety of procedures and that there is often more than one acceptable solution" (Carver et al., 2016, p. 12). Unfortunately, both pre-service and in-service mathematics teachers do not always receive the educational tools needed to teach statistical thinking (Fernández et al., 2020).

PSTs often perceive statistics as difficult to learn, which can impact their approach to teaching the subject (Leavy et al., 2013). This perception may stem from the unique nature of statistical thinking and reasoning, as well as the ambiguous influence of language and context (Leavy et al., 2013). To address these challenges, teacher education programs should focus on developing specific knowledge and skills for teaching statistics (Batanero & Díaz, 2010). Collaboration between statisticians and mathematics educators is crucial for effectively preparing teachers to teach statistics (Batanero & Díaz, 2010). When working with PSTs, Garfield and Everson (2009) suggested the educators should include the various types of knowledge of effective teachers of statistics including "offer[ing] them many opportunities to "be the students" and participate in activities and discussions as a way to deepen their own understanding of important statistics concepts" (p. 11).

Wild and Pfannkuch (1999) proposed the statistical investigative cycle for teaching statistics: *Problem* (formulating research questions that can be answered with data); *Plan* (planning how the data will be collected and managed); *Data* (collecting, managing and cleaning the data); *Analysis* (analysing the data with suitable numerical and graphical techniques and generating hypotheses); and *Conclusions* (interpreting results, and answering the original question) (see Figure 1). If findings are not satisfactory, the cycle may need to be repeated, and variability must be acknowledged whilst interpreting the results. Importantly, within this iterative cycle, students can formulate statistical questions, which necessitates "an understanding of the difference between a question that anticipates a deterministic answer and a question that anticipates an answer based on data that vary" (Franklin et al., 2007, p. 11).

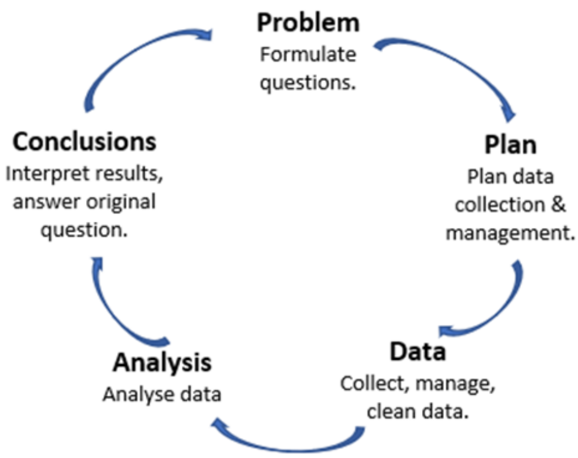

Figure 1. The statistical investigation cycle (Wild & Pfannkuch, 1999).

Generally, statistics is not taught through the statistical investigation cycle but focuses on collecting and analysing data and communicating the results, rather than posing problems and formulating a plan (Shaughnessy, 2007). In research the focus on statistics education has been data analysis (Lavigne & Lajoie, 2007). Teachers need knowledge and experience of planning and conducting statistical investigations if they are to support their students to develop statistical knowledge (Arnold, 2008). Teachers' good statistical understanding will support them to use more investigative approaches (Makar

& Fielding-Wells, 2011). Makar and Fielding-Wells (2011) believed that what is needed is "shifting teachers' epistemological beliefs about statistics from a set of methods and calculations, towards statistics as an investigative data-rich process of understanding the world" (p. 6). One method of enacting this shift is for teachers to undertake their own *"statistical investigations as learners"* (Makar & Fielding-Wells, 2011, p. 10, emphasis in the original). Smith et al. (2019) engaged PSTs in a statistical investigation aligned with a seed dispersal activity that had been previously completed by Year 5 students to develop their statistical capability. Casey et al. (2021) found that in their study across five universities in the United States that after competing their teaching and learning in statistics their PSTs designed statistical investigation tasks that incorporated large datasets and multiple cycle stages, but their statistical content tended to be mathematical, pedagogically their questions lacked clarity, and PSTs were underprepared to engage in the context or content.

More needs to be done to build PSTs understanding of statistical thinking and pedagogies to develop statistical thinking in their students. Pfannkuch and Wild (2004) suggested there are challenges to achieving this. To develop students' statistical thinking, educators need to first understand what statistical thinking is, to be able to recognise statistical thinking in different contexts, and then develop and implement teaching assessment strategies that will promote students' statistical thinking (Pfannkuch & Wild, 2004).

Experiential Learning

Kolb (1984) defined experiential learning as "the process whereby knowledge is created through the transformation of the experience" (p. 38). Kolb's experiential learning cycle (Figure 2) could facilitate the *GAISE* (Carver et al., 2016; Franklin et al., 2007) recommendation to "foster active learning."

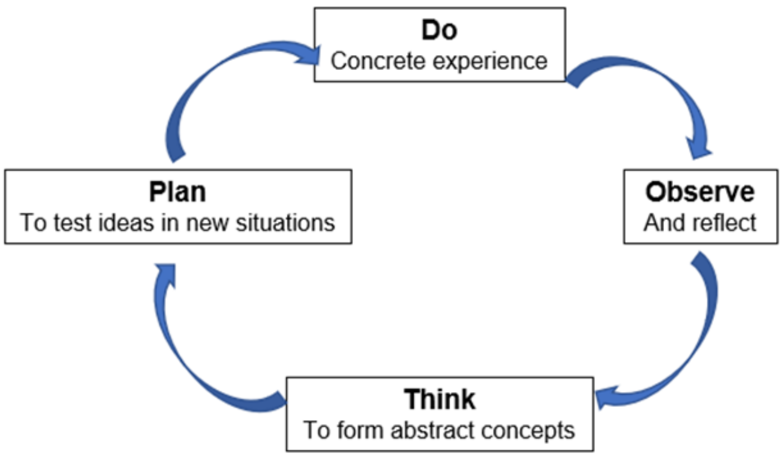

Figure 2. Kolb's (1984) experiential learning cycle.

Students first experience the phenomenon (*do*) working with a *concrete experience*. Regarding statistics, this may be collecting and comparing small data samples and using mean or median to describe the data. Students then *observe* and *reflect* on their observations with writing or discussions. The teacher's probing questions can facilitate group or class discussion, or individual reflection helping students to *think* and *form conjectures, abstract concepts, or models*. A *plan* follows, enabling ideas to be *tested in a new situation*. In experiential learning students move through the cycle: "experiencing, reflecting, thinking and acting" (Kolb & Kolb, 2005, p. 194) but not always sequentially.

Experiential learning fits within constructivist learning pedagogies where teachers pose questions and experiences that help students create personal meaning (Burns & Danyluk, 2017). These questions and experiences will challenge students' thinking (Killen, 2016) causing dissonance, which leads to "assimilating new experiences into existing concepts and accommodating existing concepts to new experiences" (Kolb & Kolb, 2005, p. 194). Hence the learning experience becomes a "catalyst for change" (Peterson et al., 2015, p. 228).

Being concerned about a "lack of empirical foundation" with Kolb's model of experiential learning, Morris (2020) proposed a revised experiential learning cycle (Figure 3). This revised cycle reflected the need for students to be physically located in a "rich contextual learning environment" (Morris, p. 1068) with opportunities to collaborate (Gibbons et al., 2018). The teacher facilitates the process, encouraging students to consider various aspects and supporting communication skills (Isaak et al., 2018). *Critically reflective observation* allows students to make meaning from the context and to draw *contextually specific abstract conceptualisations* (Morris, 2020). Students then require a new experience or context to push the boundaries of their knowledge (Grimwood et al., 2018).

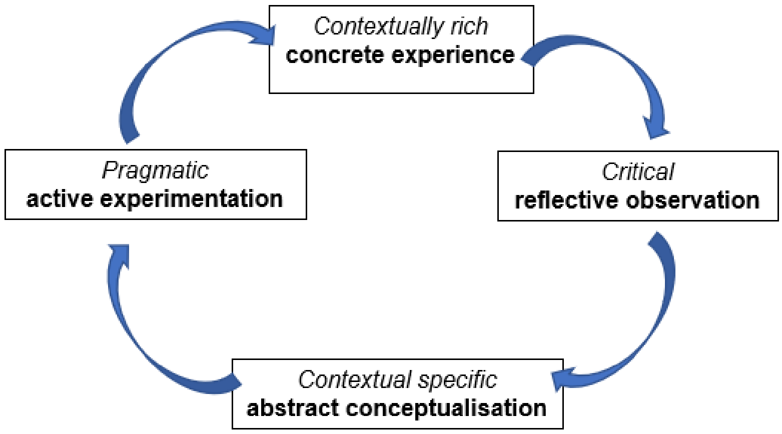

Figure 3. Morris's (2020) experiential learning cycle.

The important difference between Kolb's and Morris' experiential learning cycles is that Morris' specifies that the concrete experiences are contextually rich, and the abstract conceptualisations are contextually specific, while Kolb's does not reference the context. Morris' model extends Kolb's model by explicitly emphasising the thinking strategies required and promoting active engagement in the inquiry/learning process.

Experiential learning in initial teacher education has been used to enhance pedagogical knowledge and skills by connecting PSTs with communities (Williams & Sembiante, 2022) through community-based tutoring programs. PSTs were positive about these opportunities, saying they contributed to their literacy knowledge and skill development (Lee, 2019; Pittman & Dorel, 2014). Dillon et al. (2017) used experiential learning to teach health and physical education to PSTs and found it was useful for the PSTs to engage with the pedagogies and practices of teaching health and physical education. However, they also found they needed to explain their pedagogical reasoning for the choices and decisions, both in and on the lesson so that the PSTs could see the complexities of teaching and recognise opportunities for student learning.

Conceptualisation of the Study

Approximately half the research cohort of secondary mathematics PSTs were enrolled in an undergraduate double degree Bachelor of Education (secondary)/ Bachelor of Recreation and Outdoor Environmental Studies (BROES), with Health and Physical Education (HPE) as their first teaching area. Experiential learning was the dominant pedagogy used throughout BROES and anecdotally PSTs stated incorrectly they were using an experiential learning pedagogy in their lesson plans. To support these PSTs to consider how experiential learning could be incorporated into secondary mathematics classes, we developed some learning activities that incorporated experiential learning with statistical thinking, another application where context was important. The aim was to increase secondary mathematics PSTs' motivation to develop understanding of statistical concepts by embedding the learning activities within an experiential learning framework (Morris, 2020). Thereby, increasing PSTs opportunities to learn statistical concepts and inquiry processes.

Comparing the statistical investigation cycle (Wild & Pfannkuch, 1999) with Morris' (2020) experiential cycle, the first phase, *contextually-rich visual concrete experiences* (activities), aligns with the first three phases of the statistical investigation cycle (problem, plan, data), and the first part of analysis (sorting data, making tables, graphs, and summaries). The second phase *critically reflective observation* aligns with the second part of analysis (describing and reasoning from the data and looking for patterns). The *contextually specific abstract conceptualisation* aligns with most of the conclusion. The final stage *pragmatic active experimentation* aligns with new ideas drawn from the conclusion and moving to a new cycle in a new context. Smith et al. (2019) illustrated the utility of comparing the statistical investigation cycle with the engineering design process. In that instance, the comparison was to support PSTs in the planning of data-related activities and lesson implementation for the *Australian Curriculum: Science.*

In this article we present two *contextually-rich visual concrete experiences* (activities) (Dunn, 2024). The activities were linked to different aims within the *Curriculum Frameworks for Introductory Data Science* (International Data Science in Schools Project [IDSSP] Curriculum Team, 2019) and some of the IDSSP outcomes. The aim was that, while PSTs were experiencing the data, they were "*learning from data*" (IDSSP, 2019, p. 8, italics in the original) and developing their statistical knowledge and thinking. These activities do not address all aspects of the statistical investigation cycle, specifically not all aspects of the Analysis and Conclusion were included. The implementation of the activities was designed to support the development of conceptual understanding whilst modelling appropriate pedagogy.

The research question explored is:

> *How does an experiential learning pedagogy facilitate secondary mathematics preservice teachers learning about statistical thinking and prepare them to teach statistical thinking?*

Research Approach

Context of the Study

This case study was conducted during 2021–2022 in a regional Australian university in a single course, *Teaching Senior Secondary Mathematics*, with face-to-face tutorials. To support and supplement learning, students engaged with online materials and activities: video recordings, activities, readings, discussions, and reflections. Approximately half the secondary mathematics PSTs were enrolled in an undergraduate double degree BEd(Secondary)/BROES, with Health and Physical Education (HPE) as their first teaching area. No HPE and mathematics PSTs accepted the invitation to participate in this study only five mathematics and biology or chemistry PSTs studying a BEd (Secondary/BSc). Activities in this study were based on activities used successfully in a first-year statistics course at the same university (Dunn, 2024). Although not all PSTs enrolled in the course participated in the study, they all experienced the activities whilst learning to teach statistics, as part of the regular learning and teaching program.

Using a flipped classroom (Mustafa & Kaiser, 2022), the PSTs engaged with learning materials (short videos, readings, activities, stimulus questions and discussion boards) prior to attending each tutorial. PSTs were assumed to have statistical content knowledge. The focus of the learning materials was to develop deep conceptual knowledge for teaching, and considerations for teaching the statistical concepts. These were further unpacked during 2-hour tutorials (typically 15-30 minutes in duration per activity). The two activities discussed here focused on understanding the concepts of random, and non-random sampling, and reflecting on measures of centre (mean or median) to determine the most appropriate to use. The two activities were implemented in the same tutorial.

Participants

Following ethical approval from the university *Human Ethics Research Committee* (Approval Number A211609) and more than six months after completing the course, during which time there was no interaction with the researcher who had taught the course, all PSTs were invited to participate in semi-structured interviews. Only five PSTs agreed to be involved. During the interviews two PSTs in 2021 (pseudonyms: Debbie and Jessica) and three PSTs in 2022 (pseudonyms: Kylie, Anna, and Liam) were asked to reflect on the statistical activities experienced in the course, and whether the activities had influenced how they might teach statistics. These PSTs had completed at least one 5-week school placement.

Data Collection

Semi-structured interviews were selected for collecting the data as they provide the opportunity to probe the participant's responses (Delve et al., 2022; Kvale & Brinkmann, 2009). The semi-structured interviews, which lasted between 30 minutes and 60 minutes, were conducted and recorded via an online video conference platform (at the request of the 2021 participants and continued online in 2022 for consistency). The audio from the videos were transcribed using otter.ai, and manually checked and edited for accuracy. The images in Figures 3, 4, and 5 (see Findings section), which had been part of the teaching materials in the course, were shown via PowerPoint as stimulus during the interviews.

PSTs were asked to reflect on their experiences with the activities during the course and how they planned to teach the statistical concepts included. The interview protocol included: For the random sampling, "Did the visualisation of the different samples in the tutorial help you to understand random sampling? Please explain. Have you considered incorporating this in your teaching, and if so, how?" For measures of central tendency, "Was having to explain why the mean and median are so different a useful way to distinguish between the two measures of central tendency? What is the value of an activity where students explain how they experienced the different measures?"

Data Analysis

This study adopted a deductive data analysis strategy to analyse the data (Braun & Clark, 2006). The interview data were analysed thematically initially using Morris' (2020) experiential learning cycle (concrete experience, reflective observation, abstract conceptualisation, and active experimentation phases), specifically looking for examples of statistical thinking and how these linked with the statistical investigation cycle (Wild & Pfannkuch, 1999). For example, we determined when PSTs engaged with the different measures of central tendency (*concrete representation*) and interpreted and made decisions about whether the mean or median was most appropriate (*reflective observation*), and whether they developed conceptual understanding of choosing the most appropriate measure of central tendency (*abstract conceptualisation*). We then determined whether PSTs considered statistical thinking when planning for future teaching (*active experimentation*). Whilst analysing the data we looked for examples of statistical thinking that identified the importance of context, the presence of variability (Franklin et al., 2007), dealing with statistical variation (Watson & Callingham, 2003), and manipulating data by reduction (Kuntze et al., 2017). Because the activities did not include working through a complete statistical investigation (Wild & Pfannkuch, 1999), links were not made to all aspects of the cycle.

Findings

In this section, a description of each of the course activities implemented is provided, which is followed by the results and thematic analysis of the interview data related to each activity.

Activity 1: Sampling

The first activity addressed the IDSSP aim of "[a]voiding being misled by data" (p. 13) using visuals to help students "[e]xplain why random sampling overcomes issues of selection bias" (IDSSP, 2019, p. 43). PSTs were introduced to this activity in a course video via the course learning management system, by being asked: "What is the purpose of sampling? What is more important: how many are sampled, or who is sampled? Does it even matter? Are bigger samples always better?" The aim was to support understanding of the importance of using random sampling and identifying potential strategies to address the issue that school students often choose a convenience sample (e.g., only survey friends).

An image ("picture") was used as our *population* and PSTs were encouraged to experience, by observation, *samples* from different parts of the image. PSTs were first shown non-random samples of the image (Figure 3) in a sequence of increasing sample size and invited to guess what the picture was. The text on each slide was: "Here is a non-random sample of an image. What do you think the picture is? What led you to that thinking?" (*contextually-rich concrete experience*). On a fourth slide PSTs were asked: "If you only survey one specific part of the population, how do you know whether you are you getting the 'big picture'?" (*Critical reflective observation*). Then, the images used had simple *random* samples of pixels with the same percentage of pixels (Figure 5), and PSTs were asked the same questions.

Figure 4. Three non-random samples of an image, with increasing sample sizes (Image from https://www.pexels.com/photo/man-person-woman-face-2015/, by Gratisography [gratisography.com]).

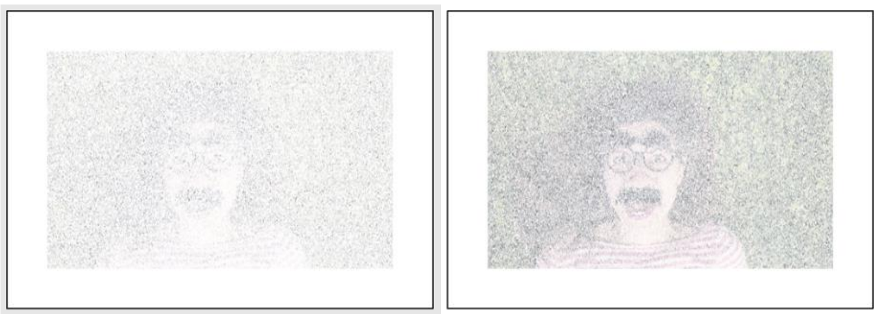

Figure 5. Two random samples of an image with increasing sample sizes (Image from https://www.pexels.com/photo/man-person-woman-face-2015/, by Gratisography [gratisography.com])

The final slide in the sequence asked PSTs to consider and comment on: "What effect did the different types of samples have?" (*Contextually specific abstract conceptualisation*) and "How could you use these slides as a teacher?" (*Pragmatic active experimentation*).

Further opportunities for *critical reflection* and *contextually specific abstract conceptualisation* were provided in the tutorial, with a discussion about the differences between the non-random and random sample, and *why* random samples better represent a population (statistical thinking). Some questions that supported the discussion included:

What did you predict the big picture was from just the non-random samples?

What was similar between the images where a portion of the sample is chosen and where the sample is chosen randomly, and what was different?

Which sample was best for seeing the "big picture" and why?

What is the advantage of using larger samples?

What is the advantage of using random samples?

Opportunities for further *pragmatic active experimentation* included a discussion in response to:

What does this then suggest for samples that you will take? and

What are the implications for your teaching?

Results for Sampling Activity

The interview data were analysed thematically using Morris' (2020) experiential learning cycle (*concrete experience, reflective observation, abstract conceptualisation, active experimentation*) and how this links with the statistical investigation cycle (Wild & Pfannkuch, 1999). During the *concrete experience* PSTs said they learnt from the sampling activity, describing how the activity highlighted the need to use a representative sample, because random samples clearly showed the variation in the data, whereas a non-random sample may only give part of the story: important to consider when *planning data collection* and then when *collecting* data. For example,

> The visualisation of sampling helped describe how fair representations in sampling is important. (Jessica)

> ... visualising the different samples helps you to understand random sampling compared to non-random sampling and how you might apply this when you *collect data*. (Debbie)

Kylie realised that a non-random sample only represented a specific part of the data:

> You can see how it can be, how it [the sampling method] can vary the results. ... how it can mislead what the data represents for the whole population. (Kylie)

Anna described how the images helped "conceptualise randomness in statistical measurement", an example of *abstract conceptualisation*. She went on to describe how only sampling the top left-hand corner would not allow "a balanced judgement" to be made, and that if the sample was not large enough then it may not be possible to "extrapolate" to the whole story:

> But what's interesting is that is that we can't, we can't necessarily see that that's a green background or vegetation or something there. So that's another interesting take on that too. ... Now we can see the shape of the face and stripy shirt, even glasses, or a moustache, for example. (Anna)

Anna had also considered that if there were not enough data, it may not be possible to say anything about the population: a larger sample is more precise: the larger the sample, the more details you can see—a *critical reflective observation*:

> That truly random sample from an entire population gives the clearest indication of the picture that is in front of us. ... if you have, I think, [larger samples] gave us an indication, but and that was of the entire population and pixels that were on that image. But at what point would the percentage become meaningless? If we only saw 1% of those, truly random sample, randomly sampled pixels in that picture? Do we have any idea of what that was? Maybe not. So, there's a threshold. (Anna)

PSTs stated that they would use the activity in their teaching (future *active experimentation*):

> I would use this [the sampling activity] as a foundation, as a starting step to kind of get students thinking, ... it's a little fun activity, ... And then I'll go in to talk specifically ... with your random sampling or your non-random sampling, how might this influence your data? If you were to do non-random, how it's impacted? You would do random, how would this impact it and talk about ... What is the strength of it or what's a limitation of it? (Debbie)

> The visualisation is an awesome way to explain the importance of randomly, true random sampling. And I think of that, when often when we start talking about sampling things at school, students will be creating or examining statistics just from their class or just from their friend group, or just from the kids that don't mind answering questions, the shy ones don't answer. And there's no real perception of, of the lack of clarity that you have on what's really going on until you use a visualisation like this; that paints a more complete picture. So, you know, this is a [future teaching] toolbox item. (Anna)

Activity 2: An Appropriate Measure of Central Tendency

Another activity delivered in a tutorial focussed on selecting "appropriate numerical ... summaries to answer questions posed about a single feature/variable in a data set" (IDSSP, 2019, p. 20). The study was designed to help students understand the differences between the mean and the median, and decide when the sample mean, or the sample median gives the best estimate of "average" for the population. In our experience, students prefer the mean as the "best" estimate of average as it uses all the data, and they often see that the mean and median are similar. In this activity, however, the mean and median are vastly different. The data were the daily river flow volume (called "streamflow") of the Mary River from 1 October 1959 to 17 January 2019. The *daily* volumes are summarised by month (Table 1, extracted from Queensland DNRM data). For example, for February the "average" *daily* streamflow could be quoted using either the mean or the median. Each month contained about 1800 observations (about 1% of the 21 659 observations are missing).

Table 1.
Monthly Summaries of the Daily Streamflow at Mary River (Bellbird Creek) from 1 October 1959 to 17 January 2019

Month	Mean daily streamflow (ML)	Median daily streamflow (ML)	Number of days
January	849.3	71.3	1783
February	1123.2	146.1	1650
March	793.9	194.9	1829
April	622.5	141.7	1770
May	348.4	118.4	1829
June	376.7	83.6	1741
July	259.3	68.8	1810
August	108.6	55.5	1829
September	100.9	48.0	1758
October	151.2	37.6	1835
November	186.6	45.3	1775
December	330.8	64.1	1834

Obtained from data extracted from the Queensland Department of Natural Resources and Mines (DNRM; http://watermonitoring.dnrm.gov.au)

Before seeing the data, PSTs were asked: "What is the mean?" The most common response was that the mean is the sum of the data values, divided by the number of values. This response explains how to calculate the mean; *calculating* the mean (mathematical thinking) does not explain what the mean represents (statistical thinking) (Bakker, 2006; Dunn & Marshman, 2020) as it does not acknowledge the context. In groups PSTs discussed whether the mean or median was the better way to measure average daily streamflow, and whether it mattered (since both measure the "average" of the same quantity). After the discussion, the means and medians were shown to PSTs (Table 1), who saw that the two statistics give *very* different values for the "average"; the February *mean* daily flow was 1123.2 ML, almost ten times greater than the February *median* daily flow (146.1 ML). Students further discussed, first in small groups and then as a class, *why* these two statistics (both measuring the "average") give such different values (promoting statistical thinking), which was the "best", and how to decide what was meant by "best".

A histogram (Figure 5, left panel) and jittered dot plot (Figure 5, right panel) of daily streamflow in February at the Mary River (Bellbird Creek) show *highly* right-skewed data with *very* large outliers. The plot of the original data, indicating the location of the mean (1123 ML) and the median (146 ML) is pointless; both are so small compared to the largest value (near 150 000 ML) that they cannot be seen; even the first bar in the histogram includes streamflow from 0 to 12 500 ML, which is much larger than both the mean and median. The maximum value is 156 586 ML, more than *one hundred times larger* than the mean (Figure 5, left panel). In fact, about 86% of the observations were *smaller* than the mean. In contrast, about 50% the values were less than the median (by definition). For these data, the mean is hardly a *central* value; medians are better measures of the "average" for highly skewed data, or data with large outliers. In these applications, often the 90% percentile is more useful anyway. Constructing infrastructure to handle an "average" situation is senseless; handling the extremes is more important.

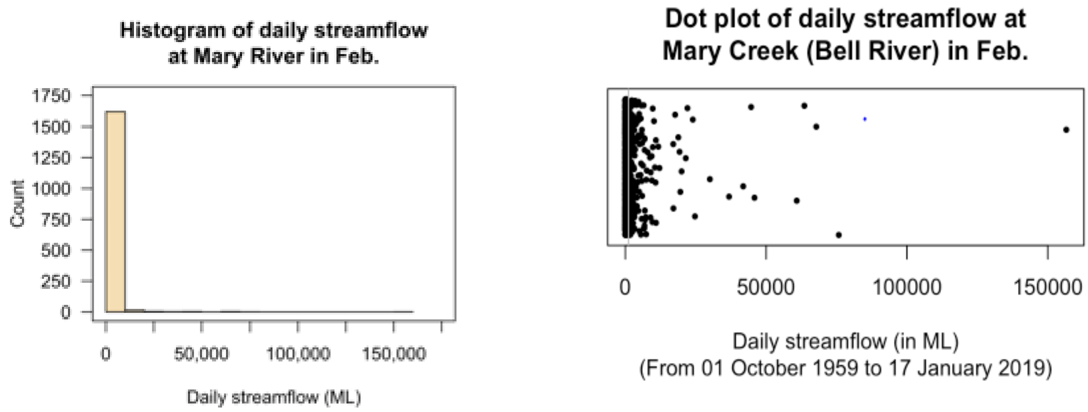

Figure 5. The daily streamflow at the Mary River in February: Histogram of the data (left panel); a jittered dot plot (right) of daily streamflow where each dot represents the daily streamflow for one day in February. The vertical line represents the mean/median (the vertical dimension has no meaning, hence is unlabelled, but is necessary otherwise most points are indistinguishable).

Results for An Appropriate Measure of Central Tendency Activity

The interview data were analysed thematically using Morris' (2020) experiential learning cycle (*concrete experience, reflective observation, abstract conceptualisation, active experimentation*) and then linked to the statistical investigation cycle (Wild & Pfannkuch, 1999). During the *concrete experience* phase PSTs worked with the data to determine whether the mean or the median were the most appropriate measure of central tendency. Hence, they were working in the Analyse phase of the statistical investigation cycle (Wild & Pfannkuch, 1999). PSTs thought the dot-plot activity was useful for learning as it highlighted the position of the outliers visually and how these outliers were skewing the data:

> … from the graph [the dot plot], you can see that majority of them [data points] chunk around the median, ... But then you can also see that there are still a bunch of outliers …, which is why you end up having those big discrepancies between [mean and median]. The outliers are affecting your average of the scores … visually, you can see that this doesn't make sense ... So not only having to explain between the mean and the median, you can also apply it to reasonableness and start having students think about

> that, too. … So, I would use it as activity with my students having them go through the difference. Write down or explain with your partner? What is the difference between these? (Debbie)

Anna thought the whole activity was useful as the different graphs provided different stimulus for inquiry questions showing how she was engaged in *reflective observation*:

> It's actually really good. I've added it to my [future teaching] toolbox. Because what a great, what a great way to visualise this in graphical form and draw it out - inquiry based learning, what's more accurate?... I think the visual is the best way [to see the variation in the data], is a great way to begin to see an overview. … I think the histogram is interesting as well. It makes you think, it drives thought and conversation about it, if I was to use it in a classroom. (Anna)

Kylie also described that sometimes that it would depend what story you were wanting to tell, indicating that she focused on the context (statistical thinking) without ensuring that she considered the definitions of median as the "middle" of the data and that the choice of mean and median meant information about the variation in the data was lost:

> I think it would depend on, if you wanting to say that there was a lot or not a lot of water in February, which one you choose. (Kylie)

Anna had personal experience of flooding on the Mary River as she had a family member who lived there and each time it flooded their home was inaccessible. She argued that one needed to consider the reason for wanting the measure of central tendency (an excellent example of statistical thinking) and that the variation in the data needed to be included (statistical thinking). Whilst Anna argued the mean was more appropriate, she should have argued to have the 90th percentile included. The mean is not a measure of the centre of these data.

> It's better to use the average [mean] because it incorporates the outliers, it allows for these outliers in the final averaged figure, whereas if we were to choose a median, … a middle point, which doesn't reflect how far we've travelled from the initial values to come to that median point. … If you want to … give a better representation of what's happened historically, then the mean is a better value to use. Because otherwise you would just omit any of the flood events. (Anna)

Anna emailed shortly after the interview to clarify her statistical thinking and highlight the importance of the context when determining a measure of central tendency (*abstract conceptualisation)* but not the definition.

> I was just thinking I could have been more specific about the different contexts around median for the Mary River and house prices. Living in a median value home is the experience for most of us. Other people owning homes of extremely high or low value does not really affect our experience of living in a home of median value. The outliers don't matter to us. When the Mary River floods, it affects everyone who lives near it or needs to cross it to get to work or the supermarket. No-one can ignore that outlier! (Anna)

The massive difference between the mean (1123 ML) and the median (146 ML) for the February data made a strong impression on PSTs that the mean and the median measure the average in different ways and hence have different meanings, and so the choice of the "average" depends on the context (i.e., requires statistical thinking). For these data, most of the streamflow values (about 86%) are *less* than the mean; by definition, 50% the values are less than the median. The mean is not really a "central" value. Any infrastructure built using a mean streamflow would be woefully inadequate. Furthermore, infrastructure would normally be built with (say) 90th percentile (1-in-decade) or 99th percentile values (1-in-century) in mind.

Discussion

Following Morris' (2020) experiential learning cycle we provided PSTs with contextually-rich visual *concrete experiences* (data to analyse/interpret) to engage in statistical thinking. These activities were simple, quick, and easy to use in large- and small-class situations; did not involve mathematics formulas but emphasised statistical thinking. In both cases, the problem had been formulated for the students and they were given the data, so they were not performing a statistical Investigation (Wild & Pfannkuch, 1999), only working with aspects of the cycle. When PSTs engaged in critical *reflective observation* they engaged with statistical thinking and in some cases developed conceptual understanding of the concepts (*abstract conceptualisation*). As PSTs thought about their future teaching during the *active experimentation* phase of the cycle (Morris, 2020), they were in the *Conclusion* phase of the statistical Investigation (Wild & Pfannkuch, 1999). They went on to say they were preparing to implement the experiential learning cycle with their students in the future.

The non-random and random sampling activity allowed students to engage Morris' (2020) experiential learning cycle. The *concrete experience* of the sampling activity provided statistical data for the PSTs to experience in the two different contexts of data *collected* randomly and non-randomly and then PSTs engaged with *critical reflective observation* as they reflected on these data collection methods. PSTs described how "visualising the different samples" had helped them understand the significance of the different sampling methods. All PSTs stated that random samples gave the clearest indication of the image. They discussed limitations in conclusions that could be drawn about a population from small samples (Anna) and how findings could be skewed with the choice of survey participants/objects (Kylie). Only one PST (Anna) described how the images helped develop conceptual understanding of randomness, an important component of statistical thinking (Gattuso & Ottaviani, 2011). These examples of statistical thinking are important considerations during the *Plan* and *Data* phases of the statistical investigation cycle (Wild & Pfannkuch, 1999) and presented an opportunity for PSTs to understand and "[e]xplain why random sampling overcomes issues of selection bias" (IDSSP, 2019, p. 43).

During *pragmatic active experimentation,* PSTs considered how they might teach sampling. They described the sampling activities as a "foundation, as a starting step to kind of get students thinking" (Anna) and a "fun activity" to "get students thinking" (Debbie). Debbie described it as a stimulus for a class discussion asking questions about the strengths and limitations of each and the impact on the data when using both a random and non-random sample. This provided an opportunity for PSTs to support their future students to understand that formulating problems and collecting quality data to answer good questions was time-consuming and difficult (Cobb, 1992) and that convenience samples will not give an accurate picture if the population was perhaps, the whole school.

In the concrete experience of working with the Mary River stream flow data to determine whether mean or median was the most appropriate measure of centre, PSTs made *critically reflective observations* as they discussed different presentations of Mary River streamflow data, which focussed on the *Analysis* phase of the statistical investigation cycle (Wild & Pfannkuch, 1999). Debbie stated that the dot plot "visually" showed that the data points were "chunk[ed] around the median", which led to the "big discrepancies" between the mean and median and how the outliers affected the mean; important considerations when analysing data. Kylie described how the graph indicated that the "majority of the points [we]re on the lower end," hence the median was the most appropriate.

As they described their *contextually specific abstract conceptualisations*, Kylie and Anna both identified knowing the purpose of the data (the question to be answered by the data) influenced the choice of measure of central tendency and information about the variation in the data was lost with the data reduction as described by Kuntze (2017). Anna's personal history with flooding in the Mary River meant she was cognisant the data reported that the "Mary River is prevalent to flooding in February." These align with the *Conclusion* phase of the statistical investigation cycle and making decisions in context; important for teaching statistical thinking (Gattuso & Ottaviani, 2011). The importance of the context focussed on statistical rather than mathematical thinking and depended on the individual's prior experiences. Anna was insistent that the flooding in the Mary River be included, highlighting PSTs were more engaged when they related to the context. Anna expressed concern for the loss of information about the highest streamflow with the data reduction (Kuntze et al., 2017). This could have been addressed by providing 90th percentile (1-in-decade) or 99th percentile values (1-in-century) values, hence, more *Analysis* and *Conclusions* within the statistical investigation cycle (Wild & Pfannkuch, 1999).

As PSTs discussed how they planned to teach sampling and most appropriate measure of average they engaged in pragmatic *active experimentation.* Anna stated she would add the activities to her future teaching "toolkit" and described how both the dot plot and the histogram were useful ways to visually draw out thinking as "inquiry-based learning" similar to the "investigative process of problem-solving and decision making" (Carver et al., 2016). PSTs stated the dot plot demonstrated how outliers skewed the mean. Debbie believed she would ask her students either, "Write down, or explain, with your partner what is the difference between these [median and mean]?" The context makes the differences between the mean and median have more meaning.

The PSTs had had previous experience with the statistical investigation cycle (Wild & Pfannkuch, 1999) and hence the learning activities focussed on here were only considering aspects of the cycle. In each case the PSTs were presented with the *Problem* and the *Data* already collected, and the PSTs were tasked with either deciding on the most appropriate sampling method or deciding on the most appropriate *Analysis* statistic to calculate. As identified by Kolb and Kolb (2005), PSTs do not always move sequentially through the experiential learning cycle. The concepts explored should have been familiar to the PSTs, but modelling a different pedagogy meant that the PSTs moved from the *concrete experience* to *reflective observation* and *abstract conceptualisation* to suit their needs. The inquiry questions that Debbie and Anna were considering during *active experimentation* were designed to help students create their personal meanings (Burns & Danyluk, 2017).

Concluding Thoughts

Prior experiences in their discipline studies meant that our PSTs wanted to use an experiential learning pedagogy in their future mathematics classes. To support these PSTs to consider how experiential learning could be incorporated into secondary mathematics classes, we developed some learning activities that incorporated experiential learning with statistical thinking another context that these PSTs had difficulty with. We investigated whether Morris' (2020) experiential learning cycle was useful for teaching statistics. Anecdotally, half the PSTs in the Teaching Junior Secondary Mathematics course stated that they were using experiential learning in the lesson plans submitted for assessment. It would be beneficial to analyse these lesson plans from the whole course in the future. Unfortunately, only five PSTs volunteered to participate none of whom were BROES PSTs, and none had said that they were using an experiential learning pedagogy in their planning. Therefore, there is potential for bias in the sample.

PSTs described the value of experiential learning for teaching the statistical concepts of non-random and random sampling and choosing the most appropriate measure of central tendency. The non-random and random sampling activity highlighted the "omnipresence of variability" (Franklin et al., 2007) and allowed PSTs to understand that "variability is ubiquitous. … [that] It must be experienced" (Cobb, 1992, p. 331), essential aspects of statistical thinking. PSTs drew on their prior experiences arguing that their personal understanding of the context influenced their interpretation of the Mary River streamflow data which is the aim of experiential learning (Kolb, 1984; Morris, 2020). The use of context ensured statistical thinking occurred rather than mathematical thinking.

PSTs described how, they would use these activities as stimulus for classroom discussions, either small group or whole class (*pragmatic active experimentation*). They described how the visual nature of the activities could be useful to challenge their students and described some of the questions they would use including asking their students to think about the strengths and limitations of different sampling methods as the students constructed their own meaning (Burns & Danyluk, 2017). The sampling activity developed statistical thinking through understanding statistical variation (Watson & Callingham, 2003). The most appropriate measure of central tendency example demonstrated the importance of context for statistical concepts (see for example, Franklin et al., 2007). This demonstrates that PSTs can engage in statistical thinking during the *contextually specific abstract conceptualisation* phase of experiential learning.

This is a small case study so the findings cannot be generalised. PSTs explained how they intended to use the activities in their future teaching during the *pragmatic active experimentation* phase of experiential learning. Some included potential prompting questions that they intended to use with their students to develop statistical thinking and a deeper understanding of the concepts as identified by the

GAISE Report (2016). The findings do suggest that for these activities, experiential learning was successful for developing statistical thinking and preparing PSTs to teach statistics. However, as Silverman (2003) cautioned, "Qualitative data collection methods, such as interview, provide valuable information about "how people see things," the methods often ignore the importance of "how people do things"" (p. 359). This suggests research that explores classroom implementation would demonstrate if PSTs followed through with their intentions, hence evidencing if the purpose of using the activities in PST education were realised. Classroom observations would also determine the fidelity of the experiential learning and the quality of statistical thinking.

Corresponding author

Margaret Marshman
University of the Sunshine Coast
90 Sippy Downs Drive
Sippy Downs, QLD 4556, Australia
mmarshma@usc.edu.au

Peter K. Dunn
University of the Sunshine Coast
90 Sippy Downs Drive
Sippy Downs, QLD 4556, Australia

Ethical approval

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Competing interests

The authors declare there are no competing interests.

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