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Definitions and models of statistical literacy: a literature review

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ABSTRACT

Despite statistical literacy being relatively new in statistics education research, it needs special attention as attempts are being made to enhance the teaching, learning and assessing of this sub-strand. It is important that teachers and researchers are aware of the challenges of teaching this literacy. In this article, the growing importance of statistics in today's information world and conceptions and components of statistical literacy are outlined. Frameworks for developing statistical literacy from research literature are considered next. Examples of tasks used in statistics education research are provided to explain the levels of thinking. Strengths and weaknesses of the frameworks are considered. The article concludes with some implications for teaching and research.

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KEYWORDS
Statistics education research; statistical literacy; models of statistical literacy; implications for teaching and research

Introduction

> Getting outside during the summer holiday is key to happiness. (*NZ Times*, 11 November, 2013)
> Kids who watch 'Sesame Street' do better in school (money.cnn.com/2015/06/ … /sesame-street-prepare-kids-for-school-study/, 8 June 2015)

In our data-driven technological society, the need to understand and to apply statistical literacy is paramount across all walks of life (Gal, 2004; Galesic & Garcia-Retamero, 2010; Giovannini, 2008; Schield, 2010; Watson, 2014). Challenging statements and research reports such as above regularly appear in media reports and the basis for decision-making should be statistics rather than feelings and beliefs (Frost, 2013; Ingram, 2015; Tishkovskaya & Lancaster, 2012). For instance, citizens need to understand that headlines such as above were determined from a sample of the population under study and the conclusions may be subject to confounding variables and sampling error. Indeed, citizens without statistical literacy may not be able to discriminate between credible and incredible information and will have difficulty in interpreting, critically evaluating and communicating reactions to such messages (English & Watson, 2016b; Gal, 2004; Galesic & Garcia-Retamero, 2010).

The importance of statistics in everyday life and work place has led to calls for an increased attention to statistical literacy in the mathematics curriculum. Professional

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organisations such as the National Council of Teachers of Mathematics (2000) in the United States and the New Zealand curriculum document (Ministry of Education, 2007) promote a critical perspective towards statistics. Franklin et al. (2007, p. 1) write that 'Every high-school with the requirements of citizenship, employment, and family and to be prepared for a healthy, happy, and productive life'. Additionally, schools are being asked to prepare students to be flexible thinkers, to be lifelong learners, and to manage complexities of an uncertain world (Ministry of Education, 2007; Watson, 2006). Having a good grasp of social statistics can help citizens deal with a complex array of issues and participate actively in public debates and assert their rights (English & Watson, 2016b). Statistical literacy is especially important in a digital age where students are constantly presented with statistics from a variety of competing sources (Frost, 2013).

Leading statistics educators such as Garfield and Ben-Zvi (2009) claim that despite the widespread emphasis on reform in the learning and teaching of statistics, statistics education is still viewed as an emerging and challenging discipline, when compared to other learning areas. Tishkovskaya and Lancaster (2010) argue that teaching statistics is challenging because it serves students with varying backgrounds and abilities, some of whom may have had negative experiences with statistics. Another reason could be that statistics education in schools focuses on the procedural and computational aspects of statistics rather than on developing conceptual understanding (Shaughnessy, 2007). The traditional emphasis on skills development has resulted in many students not being able to think or reason statistically and led to the call for statistics education to focus on statistical thinking and literacy (Moore, 1997). According to Jacobe, Foti, and Whitaker (2014), with increased expectation for teaching statistics comes the demand for tools to properly assess the conceptual understanding of learners of statistics. However, most large-scale assessments still emphasise procedures. There is a need to measure current understanding in relation to expectations set forth by curriculum documents.

Moreover, there is a lack of a clear definition of statistical literacy. Statistics educators, statisticians and researchers around the world have not reached a consensus (English, 2013; Kaplan & Thorpe, 2010; Ridgway, Nicholson, & McCusker, 2011; Schield, 2010) and hence numerous definitions of statistical literacy abound.

The purpose of this article is to review literature related to statistical literacy. The article begins by considering some definitions of statistical literacy. The next section describes some research-based statistical literacy frameworks. The final section offers suggestions for teaching and further inquiry.

Definitions of statistical literacy

Although the importance of statistical literacy is shared by many teachers, education researchers and curriculum documents both here in New Zealand and internationally, conceptions of statistical literacy vary as much as data (Batanero, 2002; Gal, 2004; Shaughnessy, 2007). Ben-Zvi and Garfield (2004) remind that given the importance of statistical literacy, thinking and reasoning, it is crucial that people working in this area use the same language and definitions when discussing these terms.

According to Wallman (1993, p. 1), statistical literacy 'is the ability to understand and critically evaluate statistical results that permeate our daily lives – coupled with the ability to appreciate the contributions that statistical thinking can make in public and private, professional and personal decisions'. We see in Wallman's (1993) definition both a personal and a societal need for our students to develop statistical literacy skills. Callingham (2007) claims that such a definition requires that students must develop not only the mathematical skills required to understand statistical information, but also an appreciation of the social context in which the data are set. Chick, Pfannkuch, and Watson (2005) describe statistical literacy as 'transnumerative thinking' where students will be able to make sense of and use different representations of data to make sense of the world around them.

According to Garfield, delMas, and Zieffler (2010), statistical literacy involves understanding and using the basic language and tools of statistics: knowing what basic statistical terms mean, understanding the use of simple statistical symbols and recognising and being able to interpret different representations of data. They distinguish statistical literacy, statistical reasoning and statistical thinking by examining the types of words that are useful in assessing the outcomes for these terms. They use words such as critique, evaluate and generalise for statistical thinking (highest levels of Bloom's taxonomy) and terms such as describe, interpret and read for statistical literacy. However, when elaborating their list, they write that an assessment in statistical literacy might include such terms as student interpretation and critique of selected news articles and media graphs as well as items pertaining to basic terms and vocabulary.

Gal (2004, p. 49) defines statistical literacy as

> people's ability to interpret and critically evaluate statistical information, data-related arguments … to discuss or communicate their reactionsto … statiscal information, such as their understanding of the meaning of the information, their opinions about the implications of this information, or their concerns regarding the acceptability of given conclusions.

In the classroom, students should be able to interpret results from studies and media reports, be able to pose critical and reflective questions about those reports and communicate reactions where required. Even if students do not perform a study, understanding statistics can help them assess the quality of other studies and the validity of their findings. Watson (2006) sees statistical literacy as the 'meeting point of the chance and data curriculum and the everyday world, where encounters involve unrehearsed contexts and spontaneous decision-making based on the ability to apply statistical tools, general contextual knowledge, and critical literacy skills' (p. 11). For Watson (2006) and Gal (2004), questioning claims in social contexts such as media reports is fundamental to statistical literacy.

Clearly, the type of statistical literacy that Gal (2004) and Watson (2006) identify is different from just being able to read and evaluate data and graphs. From the definitions of statistical literacy provided by Gal and Watson, a number of aspects entwine to create a complex construct. The emphasis on cognitive skills, contextual understanding, dispositions and critical thinking may present a challenge for teaching and assessment. A framework has to be identified to provide information about the development of cognitive skills including critical thinking and dispositions.

Statistical literacy frameworks

Despite the challenges of the terminology and definitions, it is generally accepted that statistical literacy is an important component of statistics education (Doyle, 2008; Watson, 2006). This section considers three frameworks or models that attempt to represent the features of statistical literacy discussed in the previous section. The first framework is from Gal's (2004) research into the understanding of statistics by adults. The second model is the Statistical Literacy Construct from Watson and Callingham (2003). The third framework comes from Sharma, Doyle, Shandil, and Talakia'atu (2011) collaborative study.

Gal's (2004) model of statistical literacy

Gal (2004) proposes a statistical literacy model that involves both a knowledge and certain attitude or dispositional components that operate together. According to Gal (2004), there are five interrelated cognitive elements that must be used to exhibit knowledge component of statistical literacy:

(a) mathematical knowledge;
(b) statistical knowledge;
(c) knowledge of the context;
(d) literacy skills
(e) and critical questions.

Furthermore, Gal adds that critical evaluation of statistical information (after it has been understood and interpreted) depends on additional elements as well, the ability to access critical questions and to activate a critical stance. He adds that some of these elements are held in common with literacy and numeracy, whereas others are unique to statistical literacy. Gal writes that the components and elements in the model should not be viewed as fixed and separate entities but as a context-dependent, dynamic set of knowledge and dispositions that together produce statistically literate behaviour.

According to Gal (2004), a model of statistical literacy not only focuses on aspects necessary to establish an awareness of data and critical thinking that must take place in order to consume data, but also focuses on the dispositional aspects of statistical literacy, a form of enquiry and action that an individual takes as a result of processing the information. He also examines how these knowledge bases can interact with a person's dispositions, beliefs and attitudes towards data and statistics in general. For Gal, the dispositions or associated attitudes and beliefs motivate citizens to be critical thinkers with statistics. The dispositional elements of statistical literacy skills recognise that students should adopt a critical attitude to information at all times and become *professional noticers.* He questioned the tacit assumption that students who learn to process data can transfer these skills to interpreting and critically evaluating statistical information. This is consistent with Shaughnessy (2007) who writes that although there are some overlaps between Gal's model of statistical literacy and Wild and Pfannkuch's model (1999) of statistical thinking, they are focused on different constructs, what adults need to be able to do in reading contexts versus statistical activity. According to Gal (2004), reading contexts emerge when people are at home and watching television or reading newspapers or shopping or participating in community activities. Gal points out that when a true level of statistical literacy has been reached, it allows the individual to take the knowledge bases and critical thinking skills that have been accumulated and apply them on their own to the statistical information they encounter in everyday life and workplace.

Moreover, Gal adds that anyone who lacks the skills discussed above is functionally illiterate as a productive worker, an informed consumer or a responsible citizen. Batanero (2002) suggests that while Gal's model can be useful at a macro level of analysis for understanding what statistical literacy involves and to help policy-makers to take decisions about the big ideas that should be taught at different curriculum levels, we need specific micro-level models that can be used to analyse statistical concepts.

Statistical literacy construct

The statistical literacy construct from Watson and Callingham (2003) builds on previous work by Watson (1997) where she uses the Structure of the Observed Learning Outcome (SOLO) taxonomy of Biggs and Collis (1982) from developmental psychology to categorise statistical literacy into a three-tier hierarchy with increasing sophistication: a basic understanding of statistical terminology; an understanding of statistical language and concepts when they are embedded in the context of wider social discussion; and a questioning attitude to contradict claims made without proper statistical foundation.

Watson and Callingham (2003) have developed the three-tiered view into their statistical literacy construct (see Figure 1). The model is a six-level hierarchy that represents increasingly sophisticated thinking starting from idiosyncratic to critical mathematical. At the Idiosyncratic (Level 1) and Informal (Level 2) levels, students are only merely interacting with the language and meanings of statistical terms. For the Inconsistent (Level 3) and Consistent Non-critical (Level 4) levels of the construct, students are beginning to engage with the context and uncover the statistics embedded in the context. In the last two levels of the progression Critical (Level 5) and Critical Mathematical (Level 6), students are able to be critical and challenge claims made in statistical reports and data. Watson and Callingham (2003) believe that traditional textbook questions could fulfil the requirements of levels 1 and 2 but that the same types of questions were unlikely to fulfil the need of 'providing motivating contexts to challenge students' critical thinking' and that teachers would have to seek out contexts such as media reports to motivate and engage students.

A real strength of the Watson and Callingham (2003) model is that the researchers have validated their statistical literacy scale with responses from a large number of Australian students. This has enabled them to attempt to determine how and when instruction for statistical literacy could take place and how instruction can be scaffolded to help students progress.

Both Gal (2004), with his attitudes and beliefs, and Watson and Callingham (2003) describe a need for similar dispositions in their models. There are some obvious differences between Gal's (2004) approach and that taken by Watson and Callingham (2003). Gal presents a full definition of statistical literacy along with the necessary components that are needed. However, Watson and Callingham differentiate between hierarchical levels of statistical literacy. The different approaches can be explained by the contexts of their studies into adults and students, respectively. The essence of both Gal's and Watson and Callingham's descriptions are very similar. Both emphasise a need for statistical knowledge and skills, the ability to communicate ideas, the centrality of context and the need to be critical. Watson and Callingham's (2003) statistical literacy construct has

6. Critical Mathematical
Critical, questioning engagement with context, using proportional reasoning particularly in media or chance contexts, showing appreciation of the need for uncertainty in making predictions, and interpreting subtle aspects of language.

5. Critical
Critical, questioning engagement in familiar and unfamiliar contexts that do not involve proportional reasoning, but which do involve appropriate use of terminology, qualitative interpretation of chance, and appreciation of variation.

4. Consistent Noncritical
Appropriate but non-critical engagement with context, multiple aspects of terminology usage, appreciation of variation in chance settings only, and statistical skills associated with the mean, simple probabilities, and graph characteristics.

3. Inconsistent
Selective engagement with context, often in supportive formats, appropriate recognition of conclusions but without justification, and qualitative rather than quantitative use of statistical ideas.

2. Informal
Only colloquial or informal engagement with context often reflecting intuitive nonstatistical
beliefs, single elements of complex terminology and settings, and basic one-step straightforward table, graph, and chance calculations.

1. Idiosyncratic
Idiosyncratic engagement with context, tautological use of terminology, and basic mathematical skills associated with one-to-one counting and reading cell value sin tables.

Figure 1. A statistical literacy construct (Watson & Callingham, 2003).

been identified from data which were gathered under test conditions, and the issue of providing assessment as part of normal classroom setting remains. The next framework provides information that will allow valid inferences to be made about students' understanding regardless of the context of the assessment task.

A four-stage framework to diagnose students' thinking in statistical literacy (Sharma et al., 2011)

Sharma et al. (2011) developed sequences of activities through a research-and-development process called design research (Cobb & McClain, 2004). The collaborative study involved cycles of three phases: a preparation and a design phase, teaching experiment phase and a retrospective analysis phase. In this study, teaching experiments were conducted in two year-9 classrooms.

In preparing for the teaching experiment, the research team conducted whole-class performance assessments with two groups of year-9 from the same school in which the team planned to work. The assessment was undertaken by students in normal classroom settings rather than under test conditions. The instrument consisted of eight tasks, each with a series of questions. Four questions are used to discuss the stages in the framework.

Question 1 displayed information about children's favourite junk foods in a bar graph. It required students to read information from the graph to explaining their responses and asking worry questions.

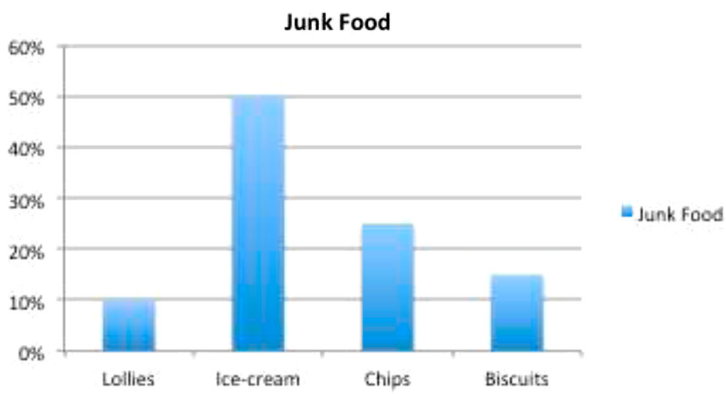
In the comparing temperatures task (Question 2), students had to compare the temperatures in Auckland and Wellington and provide some explanations about how the temperatures change. They had to question how and why the data were collected and to think of the meaning within its context.

Question 3, called the race, was set in the context of a championship. It addressed aspects of measures of centre and statistical variation. The open-ended question required students to make a choice using data provided in the form of a table and provide explanations for the choice.

Question 4 used the context of an advertisement involving *Wonder Gel*. Such statements are prolific in the media; students were expected to think statistically and critically evaluate the statement and communicate their thinking in writing.

Question 1 (Favourite junk food)

The graph shows information about children's favourite junk foods. Have a look at the graph and answer the questions below.



(a) What junk food did children say was their favourite junk food? Explain your thinking.
(b) What other information would you like before you can make decisions based on the graph? Explain your thinking.

Question 2 (Comparing temperatures)

Below are the temperatures (in degrees Celsius) on 12 consecutive days in Auckland and Wellington in September 2008.

Look at the temperatures from both the cities and answer the questions below.

Day	1	2	3	4	5	6
Wellington temperature °C	15	16	12	10	13	10
Auckland temperature °C	18	13	16	15	19	20

Day	7	8	9	10	11	12
Wellington temperature °C	13	15	9	13	8	12
Auckland temperature °C	13	11	15	15	16	15

(a) Is Auckland warmer than Wellington? How do you know?
(b) Have you got any questions about the information presented in the tables? Explain your thinking.

Question 3 (The 100-metre race)

The following table gives the times (in seconds) that each girl has recorded for seven of 100-metre races that they have run this year.

One girl is to be selected to compete in the upcoming championships.

RACE	1	2	3	4	5	6	7
Sarah	15.2	14.8	15.0	14.7	14.3	14.5	14.5
Rita	15.8	15.7	15.4	15,8	14.8	14.6	14.5
Maretta	15.6	15.5	14.8	15.1	14.5	14.7	14.5

Which girl would you select for the championships and why?

Question 4 (Wonder gel)

Mele reads an advertisement in a magazine at the hairdressers.

Two out of three Hairstylists use Wonder Gel

What questions would you have about this advertisement? Explain your thinking.

The framework is based on the Watson and Callingham's (2003) and Watson's (2006) statistical literacy construct that included six levels. The six levels identified by Watson have been reduced to four stages. Students can exhibit the stages at any curriculum level.

The boundaries between the stages are not hard edges but rather provide a set of stages that give a convenient way of describing changes as students progress to higher levels of thinking. The aim is to furnish teachers with a tool that can be used to scaffold and assess students' statistical literacy constructs.

The four stages are the following.

Stage 0–1: Informal/idiosyncratic

Students at this stage are exhibiting characteristics of pre-structural or at most uni-structural thinking (Biggs & Collis, 1982).

- There is only an informal engagement with context, often reflecting intuitive non-statistical ideas and beliefs.

- Due to reading or writing difficulty, students are unable to explain their thinking and often guess answers. With respect to statistical terminology, students provide random or inappropriate explanations. When making inferences, students focus on imaginative story telling or inappropriate aspects. Students use subjective reasoning to describe measures of centre or spread of data.
- Questions asked are not based on the data or focused on irrelevant contextual issues.
- Students are successful at some basic table and graph reading, as these require understanding of single elements and basic one-step straightforward reading.

Stage 2: Consistent non-critical

Students at this stage are exhibiting characteristics of uni-structural and multi-structural thinking.

- Students focus on a single relevant aspect or attempt to attend to one or more relevant aspects of the data but have difficulty in integrating the aspects.
- Appropriate but non-critical engagement with context.
- Accurate use of statistical skills associated with simple statistics and graph characteristics.
- Single or partially correct comparisons made within a data table or graph.
- General or single statements made about the data collection methods and validity of findings with no reference to context.
- Questions asked are valid but based on one aspect of data.

Stage 3: Early critical

Students at this stage are beginning to exhibit characteristics of relational thinking. Students at this stage can attend to more than one relevant aspect of the data and are beginning to integrate the aspects.

- There is critical engagement in familiar contexts. There is selective engagement with unfamiliar contexts with some justification.
- There is appropriate use of terminology, qualitative interpretation of chance and appreciation of variation. Students demonstrate awareness of relevant features of displays, measures of centre and spread; however, these are primarily based on the data or the context but not both.
- Questions asked of the data are based on more than one aspect of data task but not always connected.
- Students are likely to relate several elements together about data collection methods and graphing; they can manage two variables at the same time.

Stage 4: Advanced critical

Students at this stage integrate statistical and contextual knowledge that exhibits extended abstract thinking. Students have the ability to relate several aspects of a task together to use as the basis for prediction, generalisation, reflection or creation of new understanding.

- There is a critical, questioning engagement with context.

- There is an understanding of the purpose of the data, data displays, measures of centre and inferences made. There is a critical evaluation of data collection methods, choice of measures and validity of findings that shows appreciation of variation and the need for uncertainty in making predictions.
- Sophisticated statistical and mathematical skills are associated with success at this stage, especially in media contexts.
- There is the ability to interpret subtle aspects of language.
- Questions asked are based on relevant features of the data and the context using multiple perspectives.

The next section illustrates the levels of students' statistical understanding as they engaged with the above questions. Student explanations and questions are mapped onto the Statistical Literacy Framework. The four stages, although examined separately in the framework, are closely linked. For example, the ability to analyse and interpret data builds on the ability to read data displays.

At stages 0/1, the students were able to extract point information from the bar graph (Question 1: favourite junk food was ice cream) and tables (Question 3: choose Rita because she has the highest). The students could find information by directly looking at the data display or comparing the data locally. However, there was no consideration of the context or data as a distribution. Random or no explanations or questions are likely to indicate reading/writing difficulties, as the explanations could be lengthy and structurally complex. So, students used random phrases such as *They both cold*. The response, *ice cream because ice cream is sweet* indicates lack of engagement with the problem context and use of non-statistical reasoning. This misinterpretation of the task may be related to the belief that the children like sweet junk food rather than survey students about favourite junk food. When asking questions, students focus on inappropriate or idiosyncratic aspects, for example, the question: *Why do we have to select girls can't it be mixed?* may be related to classroom activities where teachers use mixed ability grouping rather than focus on selecting a student for the championship (Question 3).

Questions asked reproduce the words used in the task, for example,

> How many children don't like ice cream? What time of the year were these recorded?

The response also indicates a link to literacy skills for some students and the possible issues of reading a scenario.

At stage 2, responses indicate that statistical and literacy skills are sufficient for the problem to be understood but explanations focus on single features of data display or measures of centre, such as *Yes, the mean temperature of Auckland is 15.5C while the mean temperature of Wellington is 12C* without considering the need to integrate variability or context. Hence, it is not just knowing curriculum-based formulas such as add them up and divide by total number of values but integrating these with an understanding of the increasingly sophisticated settings within which questions arise.

At this stage, questions asked are likely to detect the critical features for representativeness or bias. For instance, *How many children were involved in the survey?* is judged as an appropriate question in this question because sample size can influence validity of findings.

At stage 3, students start to appreciate many contexts, although they cannot go further to explain/question data. In terms of questioning the Wonder gel (Question 4), students present sample size, representativeness and random ideas such as *How many hairstylists were surveyed? Was the survey random or systematic? Was the survey representative of all hairstylists?* However, there is no evidence of integrating the statistical and contextual information.

At the top stage of the statistical literacy framework, students demonstrate critical thinking skills associated with sampling, measures of centre and data display. As mentioned previously, sophisticated statistical and higher order skills are associated with success at stage 4, especially in media contexts. For the junk food question, students are likely to suggest random methods or random methods combined with representation such as *100 boys and 100 girls picked at random*.

Other frameworks

The three frameworks discussed previously are by no means the only frameworks available for describing statistical thinking or statistical literacy. Wild and Pfannkuch (1999) have developed a model for statistical thinking which built upon statistics education literature as well as interviews with statisticians and undergraduate students. The researchers have identified four dimensions: an investigative cycle, types of thinking, an interrogative cycle and dispositions. The investigative cycle or PPDAC cycle (problem, plan, data, analysis and conclusion) describes the process of statistical investigation.

Wild and Pfannkuch's second dimension states that there are five fundamental types of statistical thinking: recognition of the need for data transnumeration (or using different representations of data to give better understanding), understanding variation, using statistical models and integrating the statistical with the contextual (Wild & Pfannkuch, 1999). The interrogative cycles (generate, seek, interpret, criticise and judge) describe the thinking process that statisticians use when dealing with the problem and the data. Finally, Wild and Pfannkuch describe the dispositions that statisticians require for statistical problem-solving. Wild and Pfannkuch's dimensions are non-hierarchical and non-linear, however, the investigative cycle and the interrogative cycle are sequential.

Wild and Pfannkuch's (1999) dispositions components are *scepticism, imagination, curiosity, awareness, openness, propensity to seek deeper meaning, being logical, being engaged* and *persevering*. Under scepticism, Wild and Pfannkuch see the need to 'adopt a critical eye'. Although some of the statisticians that Wild and Pfannkuch researched believed that the dispositions could not be taught, Wild and Pfannkuch describe how the investigative cycle and the interrogative cycle, for example, can be used as thinking tools prompting students to address certain issues.

While the Watson and Callingham's (2003) and Sharma et al.'s (2011) frameworks come out of the work of statistics educators working in classrooms with students, the Wild and Pfannkuch (1999) framework comes from the researchers researching from the statistician's viewpoint and looking at what statisticians believe they do. Wild and Pfannkuch do not attempt to describe the progression or development in statistical literacy or the development of statistical concepts in students but rather outline what statisticians actually do. The focus is on describing a much wider framework for statistical thinking. This was clearly not the intention of the researchers. Wild and Pfannkuch do not see statistical thinking or statistical literacy as separate entities but rather that there is 'holistic thinking informed by statistical elements' (1999, p. 244).

Reading (2002) suggests 'profile for statistical understanding' based on the SOLO taxonomy across five areas of statistics: data collection; data tabulation and representation; data reduction; probability; and interpretation and inference. Jones et al. (2000) developed a framework for characterising children's statistical thinking. The framework provides a coherent picture of young children's thinking and their cognitive knowledge. The framework has four levels of thinking across four key constructs.

The GAISE framework (Franklin et al., 2007) identifies three levels of statistical development (levels A, B and C) that students from K to 12 progress through in order to develop statistical understanding. Grade ranges for these levels are not specified; however, ideally levels A, B and C would correspond with elementary (Grades K-5/Ages 5–11), middle (Grades 6–8/Ages 12–14) and high school (Grades 9–12/Ages 15–18). These frameworks do not specifically mention statistical literacy, although they are similar to the hierarchical framework of Watson and Callingham (2003).

Implications for teaching, assessing and research

The major purpose of this article was to document the hierarchical nature of the statistical literacy construct. Major implications for practice and research that can be drawn from this article are discussed below.

It is clear from the literature review that statistics educators and researchers around the world have not reached a consensus (English, 2013; Kaplan & Thorpe, 2010; Ridgway et al., 2011) and numerous definitions of statistical literacy abound. Hence, it is important that people working in this area are consistent in the use of language and definitions rather than use terms such as statistical thinking and statistical literacy interchangeably. Moreover, from the definitions and components of statistical literacy examined in this article, it is evident that statistical literacy is a complex construct that requires not only a range of basic skills (reading, comprehension and communication) but also higher order cognitive skills of interpretation, prediction and critical thinking. The ability to interpret statistics critically and to refute claims is not innate; these skills need to be taught if students are to become informed citizens.

The statistical literacy frameworks documented in this article can enable teachers trace students' individual and collective development in statistical literacy. The frameworks provide useful information regarding the type of statistical literacy that can be expected at different stages. The frameworks offer a coherent picture of students' statistical literacy and provide knowledge base for designing and implementing instruction.

It may be quite easy to teach students how to extract point information from data in tables and graphs (stage 1), but it may be more difficult to help them develop strategies to question how and why the data were collected, to make comparisons within and between stages and to think about the meaning of data in context. This is what the four-stage framework (Sharma et al., 2011) can help teachers do in conjunction with sound pedagogical teaching and learning of statistical concepts. It can provide a means for teachers to scaffold their students' thinking through the development of examples such as those illustrated in this article.

The questions in Sharma et al. (2011) assessment were used as paper–and-pencil test items. The written nature of the assessment satisfies at least one dimension of Gal's (2004) requirement to communicate opinions to statistical information. They can also be used as a basis for individual interviews with students where the teacher might intervene with additional questions such as who did the survey when students are unsure of their responses. It is also possible to integrate tasks like these with classroom activities. The tasks may be motivating to use with groups of students. Group responses could be assessed directly or used as a basis of classroom discussion or debate about the validity of statements. This could lead to an extended discussion about becoming critical consumers of information in the media.

While researchers have investigated students' cognitive development in statistical literacy (Watson, 2006; Watson & Callingham, 2003), few have explicitly investigated the associated dispositional component (motivation beliefs and attitudes) that affects or supports statistically literate behaviour. Ingram (2015) and Panksepp (2003) state that many higher order cognitive abilities co-evolve with corresponding affective processes. Gal (2004) explains that development of research methods in this area is crucial for understanding the forces that shape statistically literate behaviour in diverse contexts. According to Gal, changes in dispositions can be measured as part of evaluating the impact of educational interventions aimed at improving statistical literacy of all walks of life. Research questions could include:

> What are the student attitudes and motivation towards statistical literacy and the way we can teach it?
>
> How can we modify our teaching methods to improve student attitudes?

From the above ideas, it is essential to place emphasis on issues that adults may have to cope with as consumers of statistics and the implications for needed knowledge and educational experience. Like Gal (2004), I believe that attention to real-world demands should be part of the consideration that guides what gets taught, assessed and valued in the statistics classroom. The emphasis on critical thinking and contextual understanding, however, can present challenges for teaching and assessment (Garfield & Ben-Zvi, 2009; Shaughnessy, 2007; Watson, 2006). To assist teachers, a framework must be identified that will provide information about the cognitive skills, including critical thinking in socially based curriculum approaches. I believe that such a framework is likely to be dynamic in nature and can be viewed as a developmental sequence. This means that prior knowledge and experiences will influence current understanding and lead to the development of more complex statistical literacy constructs.

Existing classroom schemes of work tend to focus more on generating data rather than on interpreting or evaluating other studies or reports. The focus is on students going through the statistical inquiry cycle. School textbooks may also play a central role in statistics classroom to help students develop statistical skills and techniques. Students are expected to be able to work through the exercises by themselves with the teacher available to help them. In light of changed curriculum expectations and extended social expectations for statistical literacy, teachers across the different learning areas will have increased expectations placed on them in terms of appreciating statistical literacy and how to develop it (English & Watson, 2016a; Franklin et al., 2007; Usiskin, 2014). English (2013) claims that statistical literacy requires a long time to develop and must begin in the earlier years of schooling. It is likely that professional development for teachers will be needed (Pierce & Chick, 2013) if they are to assist their students to achieve the highest levels of statistical literacy before they leave formal schooling.

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Notes on contributor

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