UNDERSTANDING STATISTICS ABOUT SOCIETY: A FRAMEWORK OF KNOWLEDGE AND SKILLS NEEDED TO ENGAGE WITH CIVIC STATISTICS

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New technologies and new data sources require a rethink about the nature of statistical literacy. We offer a brief review of earlier conceptions, and a new mapping of the dimensions of statistical literacy that are essential if citizens are to engage meaningfully in the democratic process. Three broad headings are used: Engagement and Action (this includes: meaning for society and policy; and critical evaluation); Knowledge (this includes: methodology; and modelling); and Enabling Processes (this includes: ICT and search; and literacy). Dimensions are exemplified with tasks. The framework can be used for evaluating and revising curriculums and assessment systems.

The paper is based on the work of the authors, together with Jim Ridgway (Durham University), as part of ProCivicStat (PCS), a collaboration between six universities in five countries (Germany, Hungary, Israel, Portugal, and the United Kingdom) funded by the European Commission's ERASMUS+ program (see www.procivicstat.org). PCS aims to promote civic engagement and understanding among young adults about key societal phenomena. Mapping out key dimensions of statistical literacy is an essential element of this work.

There is a widespread belief that citizens should be able to make wise decisions, participate effectively in societal processes, and promote their own well-being (e.g. OECD, 2012). Geiger *et al* (2015) emphasize the importance of numeracy skills in the context of the demands of the 21st century. Friel *et al* (2001), in their discussion of the cognitive processes involved in understanding tables and graphs, also discuss the importance of knowledge about context. They describe *reading behind the data* (i.e. understanding context, and drawing on knowledge about the situation and the factors or processes that influenced data collection), as well as *reading the data*, *reading between the data*, and *reading beyond the data*. Citizens increasingly encounter expert predictions about probability and risk (Chernoff, 2015) in contexts such as elections, global warming, and health (e.g. the probability of getting breast cancer). These predictions are based on quite different sorts of data and modelling assumptions. Citizens need to be able to evaluate the quality of the evidence offered – this includes the way it was gathered (e.g. via a randomized controlled trial, or via epidemiology) and analyzed. Gal (2005; 2009) defines Probability Literacy as *"The ability to access, use, interpret, and communicate probability-related information and ideas, in order to engage and effectively manage the demands of real-world roles and tasks involving uncertainty and risk."* Clearly, these are essential skills for informed citizenship.

Despite these grand ambitions for citizen literacy, results from large-scale surveys of adult competence in reasoning about numerical evidence in real-world settings make rather dismal reading. An OECD survey of financial literacy of adults in 16 countries (Atkinson & Messy, 2012) found that fewer than half of the adults surveyed understood the reasons for diversifying one's investments; a study by the US National Science Foundation (NSF, 2014) based on repeated surveys of national samples of adults revealed that less than 40% of respondents understand that an experiment involves a control group; von Roten *et al.* (2013) provide vivid examples of knowledge deficits in science literacy and statistics. These results, in part, can be attributed to a lack of attention in education systems to the application of statistical ideas to real-world issues-or indeed to the priciples that underpin the whole scientific enterprise.

Here, we build on earlier work and map out some important dimensions of statistical literacy (SL); we acknowledge that the concept is dynamic, and likely to change in the face of major cultural upheavals associated with data science. Frameworks associated with Adult Numeracy provide starting points for conceptualizing SL. The model of adult numeracy in the OECD Survey of Adult Skills (PIAAC Expert Group, 2009) refers to three key categories: *responses* (e.g. locate, compute, evaluate, communicate); *mathematical information and ideas* (e.g. data and chance, pattern, relationships and change), and *representations* (e.g. technology-based displays, texts, graphs and tables). Tout & Gal (2015) discuss links between the conceptual

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frameworks for Adult Numeracy in PIAAC and Mathematical Literacy in PISA. Gal (2002) distinguishes between *knowledge elements* (such as statistics and probability, and contextual knowledge), and *enabling* processes (such as information search, and evaluation skills). Boersma *et al.* (2011) and Madison (2014) describe six core competencies that are required for responses to tasks that call upon quantitative reasoning: *interpretation* (the ability to glean and explain mathematical information presented in a variety of forms); *representation* (the ability to convert information from one mathematical form to another); *calculation*; *analysis/synthesis*; *assumptions* (the ability to make and evaluate assumptions in estimation, modeling, and data analysis); and *communication*. Literacy (in the sense of competent use of language) is an important component of SL because quantitative information is often embedded in text. Kilpatrick *et al.* (2001) and Kilpatrick (2001), describe s*trategic competence* (ability to formulate, represent, and solve mathematical problems) and a*daptive reasoning* (capacity for logical thought, reflection, explanation, and justification) in their discussions of mathematical proficiency and mathematical literacy. Statistical literacy is not simply about mastery of technique; it involves habits of mind – a willingness to engage with data – and enabling processes – the ability to reason with numerical evidence.

Below, we synthesise ideas from earlier authors, and add facets of statistical literacy that underpin the ability to engage with social issues – i.e. Civic Statistics. The core facet is *Meaning for social policy*; every other aspect of statistical literacy contributes to this facet. We identify three groups of (non-orthogonal) facets. These are elaborated, below, and exemplified via questions.

*Engagement & Action***,** comprising: Meaning for society and policy; Critical evaluation and reflection; and Dispositions

*Knowledge***,** comprising: Statistics and risk; Representations, patterns and models; Methodology and enquiry processes; Extensions in official statistics; and Contextual civic knowledge

*Enabling Processes***,** comprising: ICT and search; Quantitative core; and Literacy and communication

ENGAGEMENT & ACTION

Facet 1: Meaning for social policy

This facet is at the heart of statistical literacy – students and citizens need to be able to form a view of what could and should be done to address some policy issue, grounded in evidence. In practical settings, decision making is associated with weighing existing evidence, and also with notions of risk – probabilities, costs and benefits, expected values, and subjective utilities. There is a need to address not only the immediate impact of any proposed policy change, but also the knock-on effects of any course of action. So an analysis of likely social impact is needed to complement statistical analysis and any recommendations.

In many European countries the population is increasingly dominated by old people. What are the implications for pensions and health care? What actions might be taken, and what 'unintended consequences' need to be considered?

Facet 2: Critical evaluation & reflection

'Post-truth' and 'alternative facts' are attacks on the heartland of informed decision making. Even when using data from well-authenticated sources, there is still a need for critical evaluation and reflection. Critical evaluation and reflection should be habits of mind – questions one triggers routinely without much conscious effort. For example:

- What is the story being told – whose story, and why are they telling it?
- Has the problem been identified appropriately?
- What evidence is being presented? From a credible source?
- Have appropriate statistical models been chosen (e.g. is it OK to assume data are normally distributed? Has linearity been assumed?)?
- What else could be going on – a confounding variable?
- Are the conclusions consistent with the evidence?

A study shows that recent migrants are below average intelligence. Identify 3 distinct factors that might invalidate the conclusions from this study.

Facet 3: Dispositions

Great skills with statistics are unlikely to be useful in everyday life unless they are associated with positive dispositions. Dispositions are emotional responses associated with a willingness to engage in evidence-based argument. Negative dispositions are exemplified by statements such as 'lies, damn lies and statistics'. Positive dispositions are exemplified by the actions of fact checking organisations such as Full Fact and chequeado who offer non-partisan commentaries on statements by politicians and in the media.

Dispositions reflect a complex web of motivations, beliefs, and attitudes. They have a social dimension, such as a willingness to share interpretations with others. They have components (e.g., self-efficacy, confidence) that affect engagement in both positive and negative ways. Dispositions about one's own state of knowledge are important. Ignoring evidence because of prior beliefs, accepting new information uncritically, or believing that social phenomena can only be understood by experts are all symptoms of unhealthy dispositions. Healthy dispositions are exemplified by positive habits of mind – when faced with evidence and argument, routinely asking questions such as:

Can I play with the data myself?

Can I find other information to confirm or disconfirm the stories being told here?

Do I need to boost my own knowledge (e.g. of some new technique) and, how?

This facet is not easy to assess with a written question! Indirect evidence would be persistence in exploring (say) web-based resources relevant to a contemporary issue.

KNOWLEDGE

Facet 4: Statistics & Risk

This facet includes much of what is commonly taught in introductory statistics courses. Basic topics in statistics relevant to Civic Statistics include: samples, populations and representativeness; variability; describing and comparing distributions; association and correlation; regression; non-linearity; signal and noise; interaction; Bayesian inference; bounded estimates; and effect size. Understanding risk is an essential ingredient of Civic Statistics. It relies on probability and conditional probability (including Bayes' theorem), expected values, utility and subjective utility.

Civic Statistics also requires an understanding of some of the ideas around Big Data - such as familiarity with a wide variety of data sources and associated techniques of analysis, notably those used for detecting patterns.

Jim will spend a month in Paris. Put these sources of danger in order from highest to lowest.					
Terrorist incident		traffic accident		Shark attack	
Explain your answer.					

Facet 5: Models, patterns, and representations

All models are wrong, but some are useful (Box & Draper, 1987, p424)

The heartland of statistics is the application of mathematical models to situations of interest. An essential component of Civic Statistics is understanding that when modelling complex social phenomena, qualitatively different models can be used to model the same phenomenon. For example, an economist and a sociologist might have quite different theories and methods for defining and studying "poverty" and have quite different theories of causality. Civic Statistics requires the ability to identify and understand the use of models, and to be able to challenge the fundamental assumptions made by any model.

Representation is a core skill in understanding phenomena. Civic Statistics requires familiarity with sophisticated representations including those that are dynamic and facilitate interaction. There has been a recent explosion in the use of ICT-based representations - Civic Statistics requires the ability to understand and critique novel representations.

The Normal distribution has been used to predict the occurrence of unusual events such as floods, storm severity, and stock exchange movements. Suggest a better model, or class of models.

Facet 6: Methodology & enquiry processes

Civic Statistics requires an understanding of the strengths and weaknesses of different discovery methods, and some procedural skills. Quantitative methods include: survey research (survey types, sampling methods, with attention paid to vulnerability to bias); and experiments (naturalistic, RCTs, with attention paid to threats to validity). Topics include: sampling and randomization; measurement (reliability and validity); questionnaire design; web scraping. Qualitative methods include: interview techniques; descriptive studies; text and image analysis; and use of tools for analyzing social media (e.g. Twitter, Facebook, Instagram, blogs).

An understanding of ethical issues associated with the production of data and the use of various research methods is also an essential component of Civic Statistics, such as the need to know about issues of confidentiality and protection of the identity of citizens.

You are asked to estimate the number of people in your country living in poverty. You have access to employment data (including wages), google search data, twitter streams, and data on the number of food banks.
Choose TWO sources and say how you would use them. Justify your answer.

Facet 7: Extensions in official statistics

Official statistics producers are a major source of evidence about social issues, but many of the core ideas they use receive little attention in traditional statistics courses, such as: survey design (and associated problems such as non-response or respondent bias); measurement issues (reliability and validity; metadata definitions); techniques such as moving averages, seasonal adjustment, case weighting and data smoothing; synthetic methods where data gathered by conventional survey data is combined with Big Data (e.g. data on mobile phone traffic or web search data).

In country A the number of unemployed people is published each month. In country B, a 12-month rolling rate of inflation is published each month. Identify one important feature of each measure. Justify your answer.

Facet 8: Contextual civic knowledge

Statistics is about modelling, and in order to model, one needs to have an understanding of the phenomena being modelled. Some of this can be factual knowledge – knowing that absorbing one million refugees in Germany (population about 80 million) is likely to be easier than absorbing one million refugees in Hungary (population about 10 million), other things being equal. Knowing that other things are certainly *not* equal requires deeper contextual knowledge. Contextual civic knowledge includes: factoids such as sizes of populations, size of GDP, national debt and resources; demographics; history and geography; regional- and geo- politics. A benefit of contextual civic knowledge is that one can look for alternative data analyses using knowledge of plausible covariates. At a higher level, if one is to understand (or do) anything about social injustice, one needs to understand communication channels and governance.

In *your* country what is the current GDP, deficit, and national debt?

ENABLING PROCESSES

Facet 9: ICT & search

Initiatives such as data.gov in the USA and data.gov.uk in the UK aim to support the democratic process by giving citizens access to data that can stimulate debate and inform policy making. Many major data providers (such as national statistics offices, Eurostat and OECD) make data publicly available – however, accessing and working directly with such data sets often requires considerable technical expertise. Big Data is another important source of information for Civic Statistics. Examples include data from wearable devices, transactional data from mobile phones, and data scraped from web pages. Civic Statistics requires an understanding of the analytic techniques suited to accessing and analysing high-volume unstructured data.

ICT skills are required to engage with ICT-based tools such as statistics packages. For Civic Statistics, students must use interactive displays effectively.

What is 'webscraping'? Give an example of how it might be used to identify a social trend of your choice.

Facet 10: Quantitative core

Quantitative skills underpin all aspects of statistical literacy. Components include number sense, ratio, percentages, rates and fractions. Number sense is about having a feel for numbers. In Civic Statistics, very large numbers are common, and seemingly large resources may actually be small, in context. It is easy to find examples where an author has deliberately chosen to report (accurately) data that are misleading – for example, reporting a percentage increase, where the absolute number of the starting value is very small.

In country A, the number of deaths from alligator attacks rose 300% in a six-month period. A politician calls for 'gator nets' to be erected around all swamplands. Explain why the data should be treated with caution.

Facet 11: Literacy and communication

A great deal of information is presented as text and image in print. Text is often very dense, and being able to read fluently and absorb the overall sense of an article is an essential skill. However, both literacy and communication are moving targets. New forms of communication are emerging, that include social media, new ways to visualize data, and video. Citizens need to be able to learn how to understand and deconstruct messages conveyed in these new communication forms. For engagement in Civic Statistics, citizens need to be able to communicate in new ways.

"The rate of change of immigration is slowing" Suppose the number of immigrants is decreasing. Draw a graph or graphs and write an explanation in words, to explain the sentence in quotation marks.

Ridgway *et al.* (2017) show how these dimensions can be displayed as a radar plot that can then be used to analyse tasks, curricula, and assessment systems. The ProCivicStat project is creating resources to help students develop appropriate skills in statistical literacy.

USING THE FRAMEWORK

Here, we have presented the whole framework, in order to provide an overview. Details of each facet are necessarily sketchy; they will be amplified and exemplified in later documents. The framework has two distinct uses. One is to provoke discussion about the needs of statistically literate citizens. We have build on earlier descriptions of statistical literacy, and have introduced new elements. However, we are aware that the framework will need to be revised in the light of emerging developments in technology, such as new forms of data visualization, new ways to access tools, and new methods of analysis that will become commonplace (such as those associated with predictive policing, or automated decision making in a variety of fields), and new methods of accessing and communicating information.

The second use is in curriculum analysis and planning. An associated tool (Ridgway *et al.* 2017) presents the framework in the form of a radar plot, where each dimension appears as a radius. Individual episodes in curriculum activities, or sections in a text, or items on a test or examination can be rated on every dimension. A judgement can then be made about the overall balance of activities, texts, and tests. If a curriculum designer or teacher feels that a dimension or group of dimensions has been neglected, they can look for supplementary materials. An ambition of the PCS project is to provide some of these materials, and to link to useful resurces.

CONCLUSION

Large scale surveys show that many citizens are unable to reason with numerical evidence encountered in everyday life. In part, this is a result of curricula that place too much emphasis on mathematical and statistical technique, and not enough emphasis on understanding data from realistic contexts. If curricula are to be reformed, there needs to be a clear statement of educational

goals, with appropriate exemplification, and curriculum materials to support student acquisition of these goals. An analytic framework is presented here which describes the dimensions of statistical literacy, that can be used to analyze current curricula and assessment systems, and guide future curriculum development.

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