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MATHEMATICAL LITERACY AND CITIZEN ENGAGEMENT: THE ROLE OF CIVIC STATSTICS

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This paper explores a possible expansion of the conceptualization and implementation of mathematical literacy by describing a subfield we call civic statistics *which focuses on understanding quantitative and statistical information about society as provided by the media, statistics offices and other statistics providers. Understanding of civic statistics is required for participation in democratic societies, but involves statistics that often are open, official, multivariate in nature, and/or dynamic, which are usually not at the core of regular statistics instruction. We outline some specific characteristics of civic statistics and describe implications for curricula, teacher activities and for the future of mathematical literacy in schools.*

BACKGROUND

Knowledge and skills to reason adequately with data are an important prerequisite for the functioning of democracy in our modern and large societies. For example, in a society that aims to keep up with promises of equity and fairness to everyone, questions as to whether women, minorities, or people with disabilities are disadvantaged in their career options, wages, or access to [higher] education or to services, have to be judged largely on a quantitative level and require statistical knowledge. In an increasingly complex world, citizens' input is a critical resource for policy-makers at the national and local levels, and implementing difficult decisions on controversial social topics depends on citizens' consent and support. Unless citizens understand and are engaged in the decision themselves, trust in political decision making is easily lost (OECD, 2009).

However, achieving the goal of citizen engagement implies the necessity to equip students and [young] adults with the knowledge, skills, and attitudes needed to understand the data and engage with the statistics involved. Good citizen engagement can support the effective functioning of democracy, the legitimacy of government, the successful implementation of policy and the achievement of social outcomes. Bad engagement practice can lead to poor decisions, and disengagement by citizens (Brodie et al, 2011). Sound evidence-based decision-making in private as well as public life requires quantitative reasoning skills, and (at least as important) positive attitudes i.e. a willingness to engage with statistical data.

The above implies that an important goal of schooling should be to prepare graduates to become engaged and informed citizens. Yet, "citizen engagement" does not have a natural home in the school curriculum; the knowledge, skills, and dispositions it requires are distributed among multiple school subjects. We propose to expand or at least revisit from a critical perspective extant conceptualizations of mathematical literacy at the school level, as well as their actual implementation via statistics education as traditionally taught in schools, as we believe that at present they do not adequately address the broader issues of citizen engagement. Accordingly, this paper proposes to expand the conceptualization of mathematical literacy (Geiger, Goos, & Forgasz,

2015), by describing a subfield we call *civic statistics*, sketches some of the unique aspects of the knowledge, skills and attitudes subsumed under civic statistics, and outlines implications for curricula, teacher activities and for the future of mathematical literacy in schools. The paper reflects work-in-progress as part of a new multinational project, ProCivicStat, funded by the ERASMUS+ program of the European Commission, as well as our own ideas.

CIVIC STATISTICS: CONCEPTUAL MAP AND CHALLENGES

Statistics nowadays is part of the school curriculum in most countries. Yet statistics education both in high school and colleges is lagging behind the demands for informed citizenship as described above. To be fully engaged, citizens need to be aware of and understand statistics regarding past trends, present situation, and possible future changes in demographics, employment, wages, migration, health, crime, poverty, access to services, energy, education, human rights, and other domains. Statistics and data about these and related topics are collectively called here "civic statistics". Information about civic statistics is provided by official statistics agencies and other public and private/non-profit statistics providers (e.g., Gapminder), and some of it is mediated to the public via the print and visual media. Understanding of civic statistics is required for participation in democratic societies, but involves statistics that often are *open, large-scale, official, multivariate in nature, and/or dynamic*. Such statistics are usually not at the core of regular statistics instruction. Thus, schools and educators face the challenge to teach quantitative and statistical skills needed to understand and interpret civic statistics.

Figure 1 lists sample statistical topics in civic statistics. The list does not aim to provide a comprehensive framework of all aspects of civic statistics, but rather only to illustrate the point that there are unique aspects of civic statistics that differ from regular material learned in a standard statistics curriculum. Basic mathematical themes include percentages, proportional reasoning, relative and absolute frequencies and, on a deeper mathematical level, functional modeling. However as Lloyd & Frith (2013) demonstrate, the mastery of proportional reasoning is difficult for many high-school graduates and they have trouble to reason about everyday issues involving proportionality ideas. While percents are a basic tool in reporting about social phenomena, civic statistics extends much further. Relevant datasets (e.g., social and health studies) often have a more complex multivariate structure than the data students work with when they learn statistics in math classes. Civic statistics is *not* about understanding the mathematical foundation of highly sophisticated multivariate statistical procedure as often applied in social science research (e.g., factor analysis or multivariate regression). Rather, it involves understanding of multivariate *phenomena* and is based on developing sound heuristics, including the confrontation with biases and fallacies. *Contextual knowledge is indispensable*, but it also involves a certain statistical and mathematical knowledge and requires a critical stance and critical thinking skills. For teachers, these topics address issues beyond teaching technical skills for analyzing data and concerns matters of value clarification, understanding and embracing the principles of human equality and dignity - topics that address the mind and the heart. Moreover, it lets students experience that statistical analyses play a role in understanding pressing social and political issues of our time.

Exploring authentic data on topics about society incites discussion and reflection about central statistical issues like operationalization of relevant variables and their measurement, methods of data collection, the choice of relevant covariates and the role of potential confounders.

How can one develop concrete measurable definitions for the concepts involved? How does one define deprivation of cultural rights, economic discrimination or restricted access to public services? Even commonly used concepts like the unemployment rate are far from trivial to define. The operationalization of a complex concept such as discrimination is not easy and involves philosophical, ethical and cultural aspects. This discussion offers challenges and opportunities to enrich the discourse in the classroom.

Reasoning about large scale multivariate datasets and understanding their features via graphical representations requires different skills than the analysis of small samples that dominate today's curricula. It involves understanding of various multivariate data displays such as scatter plot matrices, spider web graph or (regression) trees. Making sense of multivariate data necessitates an awareness of other constructs that are seldom included in the introductory statistics materials at the high-school level, such as interactions, confounders, and non-linear relations. Understanding trends in large-scale civic statistics data requires an appreciation of the complexity of statistical indicators such as "mortality rate", "life expectancy" or “Gini idex”, and the underlying statistical modeling. There is also a need for the capacity to employ exploratory techniques and basic knowledge about methods of data collection and metadata, and understand the central role of qualitative variables in describing social phenomena and issues. As Ograjensek & Gal (2015) argue, qualitative (or categorical) variables relate to entities that have no natural or logical order, such as residence type or occupation; such variables enable us to answer questions such as “what type” or “what are the different kinds of”. However, these authors point out that qualitative variables present a tension to mathematics educators as they do not have an implicit numerical nature and their use requires value judgments.

1. The use of qualitative variables and qualitative reasoning when planning and designing surveys about social phenomena
2. Operationalization of the data and the use of household or CAPI-based survey methodologies (How were relevant variables defined? How were the variables measured? What are the limitations in a phone survey compared to a household survey?)
3. Knowing the need for metadata, and information about data quality and origin (How and when were the data collected? Are the responses truthful and trustworthy?)
4. Understanding conditional probability of social phenomena in subgroups
5. Understanding functional relationships/associations and interactions (in graphical and tabular forms), and the possibility of changing relationships in different levels of aggregation (Simpson’s paradox)
6. Using basic visualization and tabulation tools provided by statistics providers
7. Critical reading and thinking about texts in press releases from statistics providers (e.g., about confounding variables, correlation vs. causation) and ability to develop a story from trend data that show changes over time
8. Politics and conventions of data collection and reporting by official statistics providers
9. Understanding population projections and underlying ideas and modeling
10. Understanding social indicators, (e.g., mortality rate, life expectancy, poverty line, Gini Index), how they are derived, their use and limitations

Fig 1: Sample statistical topics related to Civic Statistics *(Note: preliminary list, under development)*

IMPLICATIONS FOR CURRICULA AND TEACHER PREPARATION

There are serious problems with the ways that statistics is taught in most countries in high school and at the introductory undergraduate level (for an international review, see Batanero, Burrill, Reading, 2011). Few high school teachers in mathematics or social science receive any training on how to teach statistics. As a result, teachers stay within their comfort zone and overemphasize a narrow range of statistical techniques and computations (mathematics), and often fail to engage with deeper statistical ideas. Thus, teachers pay too little attention to working with and understanding multivariate data that describe social trends, and to the analysis, interpretation and communication about the meaning of such data. Most statistics curricula focus on single (or perhaps two) variable problems, on technical mastery of mathematical techniques developed over 100 years ago; they use artificial data; and they make little use of modern data visualization techniques.

Statistical techniques taught and data sets used in current curricula (at the high-school and introductory university levels) are misaligned with the needs of engaged citizenship as envisioned above. Attention in math & statistics classes focuses too much on mastery of traditional technique (e.g., regression formulas, analysis of variance) and mathematical underpinnings, and on simple datasets, rather than on the skills required for understanding patterns and changes in socially meaningful phenomena, such as complex graphs and aggregate tables, and discussing underlying causal factors. There is little attention to statistical thinking, and no exemplification of the power of statistics as an aid to understanding social (or other) phenomena (Ridgway, 2015).

Many of the relevant civic statistics are collected and reported by official statistics agencies and other providers who nowadays make them open to the public, yet including them in teaching implies particular challenges. Effective understanding of data from such sources requires different skills and knowledge than the more traditional content included in existing statistics teaching. Key skills involve a critical appreciation of data provenance and quality, of metadata information, and an understanding of statistical ideas associated with analyzing large multivariate datasets. Inferential techniques like hypothesis testing may be less relevant when analyzing very large data sets. Instead, important ingredients of multivariate thinking imply the search for interactions, awareness of confounders, understanding pros and cons of aggregation or disaggregation of data (e.g., Simpson’s Paradox); benefits and costs of observational studies and surveys vs. (controlled) experiments, etc. Important mathematical methods, supported by technology-based visualization tools, include discovering and modeling functional relationships between two or more variables, including exploring nonlinear relationships, exploratory smoothing techniques, and more.

CONCLUSIONS

The concept of civic statistics promotes the empowerment of young people by developing their ability to understand evidence about key social phenomena that permeates civic life such as about migration, health status, economic equality or unemployment among different subgroups. This paper highlights the need to expand the conceptualization of mathematical literacy, and consider the "place" of civic statistics in high school mathematics curricula and in teachers' thinking, while acknowledging dilemmas in the high school context. There are many applied ramifications for the ideas above that cannot be fully developed here due to space limits, regarding needed teacher

training and professional development, needed support materials, and modes of integration within the high-school curriculum. Examples for some possible directions for implementation are:

(1) the need to address Civic Statistics as part of the statistics component of high-school mathematics curricula, even replacing some of the procedural statistical content, to improve relevance of instruction to the goals of mathematical literacy. This requires updating existing curricula in line with extant models of quantitative reasoning (Madison, 2014) and teaching-training frameworks, and developing specialized professional development materials. For instance, Lampen (2015) argues for the need for teachers to develop a statistical view of mathematical constructs, using a narrative approach.

(2) possible project work that students may do in schools which allow students to do cross-curricular activities or independent projects that involve interpreting statistics about society in context. Such work could focus, for instance, on analysis of data about important social phenomena that are taken from official sources, and follow structured analytic steps such as the framework offered by Kemp & Kissane (2010) and group discussions such as used by Prodromou (2015). However, it is imperative to remember that civic statistics is about much more than just analyzing data in tables or graphs, as much information is presented to the public via textual means (e.g., press releases).

(3) it is possible to encourage mathematics teachers to collaborate with teachers from other relevant disciplines (e.g., related to society, political science or citizenship studies) so as to include a focus on specific societal issues such as demographic trends, migration, equality etc., with emphasis on statistical work that the mathematics teachers can support.

In our presentation we can further develop these ideas and illustrate the unique aspects of civic statistics. We will discuss implications for the future of mathematical literacy in schools, and directions for relevant future research. Further ideas and materials relate to the promotion of civic statistics at the high-school and tertiary levels are being developed by the aforementioned ProCivicStat project, established to promote youth engagement with data about society that all citizens encounter and need to understand. The project aims to develop integrated resources (lesson plans, data visualization tools, and support materials) that can enrich statistics and mathematics instruction at the secondary and tertiary level through innovative open online learning materials, and contribute to the strengthening of civic society.

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