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Fabienne Crettaz von Roten

This paper explores arguments in favor of a public understanding of statistics and suggests its possible contributions to the analysis of surveys of attitudes toward science. Statistics permeates all aspects of life—from education, work, media, and health, to citizenship. For example, most media reporting includes statistical references to health, social and demographic trends, education, and economics. The pervasiveness of statistics poses a problem, as statistics is a difficult discipline associated with misunderstandings, which ruin trust and lead to misgivings. Civic scientific literacy covers statistics insufficiently, both theoretically and empirically. Finally, this paper formulates new explanations, built on statistical literacy, of empirical results found in surveys of attitudes toward science and suggests modes for the development of statistical literacy in this context.

1. Introduction

The expression "public understanding of science" (PUS), developed in the 1980s, refers to efforts aimed at promoting scientific literacy for increasing public support toward science (the more the lay people know science, the more they will love it). These efforts were synthesized through the "deficit model" which "adopted a one-way, top-down communication process" (Miller, 2001: 116). Over the years, the deficit model was criticized both conceptually and empirically (Wynne, 1995; Evans and Durant, 1995; Miller, 2001). A new communication model was proposed, namely the "engagement model," based on three D's—dialogue, discussion, and debate. Nevertheless, "the end of the deficit model does not mean there is no knowledge deficit" (Miller, 2001: 118). It is important for citizens to be scientifically literate to understand and participate in public discussions of scientific issues, and more generally to function fully in a modern society.

Therefore, elaboration upon what kind of scientific knowledge citizens need remains topical. Do they need scientific facts, scientific process, or statistics? The first two kinds of knowledge have garnered much attention; however, the last one has gained little notice, despite several arguments in its favor. As statistics is one discipline of science, scientific knowledge necessarily includes statistical knowledge. However, other arguments, which distinguish statistics from other scientific knowledge, are more relevant. First, statistics is an interdisciplinary discipline, prevalent in modern science, and thus, second, statistics permeates many aspects of modern societies. Finally, just as scientific literacy has been used to explain the relationship between science and society, statistics could provide explanations of

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empirical results found in surveys of attitudes toward science such as the knowledge–ignorance paradox, the increase in ambivalent attitudes toward science, or the unclear relationship between knowledge and attitudes toward science.

The purpose of this article is: (a) to develop reasons linked with society and statistics for a public understanding of statistics, (b) to examine if the concept of civic scientific literacy covers statistics sufficiently, and (c) to provide some arguments showing the usefulness of statistical literacy in empirical works on surveys of attitudes toward science.

2. A statistics-rich society

We live in a statistics-rich society: statistics permeates many aspects of life—from media, health, and work to citizenship. In the media, we can observe a growing emphasis on statistical results. This is particularly the case in health and medical reporting which tend to be the most compelling scientific issues for citizens according to surveys of attitudes toward science. The understanding of the statistical elements is an integral part of the understanding of this reporting. In addition, citizens are exposed to probabilistic estimates made by weather forecasters, physicians, and genetic counselors, to name a few. Furthermore, the basic requirements for employment encompass, in addition to reading, writing and arithmetic, quantitative or statistical competencies. Finally, most major public issues, from health care to social security, depend on data, and/or projections: "I find it hard to think of policy questions, at least in domestic policy, that have no statistical component" (Moore, 1998: 1253). The understanding of these statistical components is crucial to help citizens participate in public debate and arrive at political decisions.

In summary, citizens encounter statistics in multiple life contexts: as readers, listeners, viewers, workers, or actors in community activities, civic duties or political events. H.G. Wells's prophecy, at the beginning of the twentieth century, "statistical thinking will one day be as necessary for efficient citizenship as the ability to read and to write" (cited in Billard, 1998: 322) seems to have become reality. Thus, statistics should feature prominently in citizenship education.

However, the importance of statistics in our daily lives appears worth mentioning only if it causes problems. In fact, most citizens do not have the knowledge required to understand the statistical elements much less to analyze them critically and independently.[1] Popular conception of statistics suffers from ignorance, but also from misunderstandings, misperceptions, and mistrust (Wallman, 1993).

3. Statistical misunderstandings

Statistics requires the ability to consider things from a probabilistic perspective, and to employ quantitative technical and abstract concepts such as significance, margin of errors, and representativeness. Since these concepts are difficult to understand, statistical misunderstandings can often be observed in the everyday but also in the media and research results. It is important to clear up these misunderstandings, as they lead to the misuse of study results, and the development of a distrustful or cynical attitude toward statistics. These misunderstandings are the subject of many statistical papers or books (for example Huff, 1993; Helberg, 1995; Utts, 2003) and the concern of most statistics teachers and statistical societies.

For the purpose of this article, three topics have been selected, each of which will serve to illustrate different kinds of problems considered to be at the origin of these misunderstandings.

- *A significant result does not imply practical importance*. This first topic serves to illustrate the case of when a term has a different meaning in statistics than in everyday life. Since "significance" may be defined as the quality of being important (Merriam-Webster online English dictionary, http://www.m-w.com), there is a strong tendency for people to equate "statistical significance" with importance of results. However, to call something statistically significant is not equivalent to calling it important. Importance can only be handled by effect size or power test calculations (Cohen, 1992; Crettaz von Roten, 1998). This misunderstanding is not specific to lay people; even researchers, often obsessed with significance, sometimes do not pay attention to whether their findings are important. Citizens should be encouraged to ask themselves about the practical importance of significant results.
- *A significant relationship does not imply causality*. In this instance, the problem stems from the misinterpretation of correct results. The interpretation of correlation (or other relationship measures), in terms of causation, is the most common misinterpretation of results. Assessing causality implies random assignment in an experimental study—regardless of the statistical methodology used (Barnard, 1982; Cox, 1992). In other words, observational studies are limited in their ability to illuminate causal relationships. Therefore, it is important to resist the temptation of making a causal conclusion in observational studies. Even if the causal conclusion seems logical or may be explained theoretically, some confounding variables may be the cause of the observed effect. When confronted with a significant relationship, one should always look for confounders that could provide alternate explanations for the observed effect.
- *Graphs should be read fully and critically*. Statistics should be practiced actively so as to avoid being manipulated or led astray. This is especially true when statistics are represented graphically. Graphs are one familiar mode of communicating statistical messages. Sadly, many graphs, especially in the media with its tendency toward sensational reporting, are designed to mislead, highlight, or hide a specific trend or difference (Huff, 1993). To quantify this problem, Tufte's (1983) "lie factor" indicates the relationship between the data and the graphic.[2] As it cannot be ensured that graphic producers have followed the guidelines to guarantee graphical integrity, it is important that citizens develop skills to understand graphs, be able to read them critically and ask questions such as is the graph drawn appropriately, is any information missing, does it distort trends in the data?

For these reasons, namely the presence of a statistics-rich society and the pervasiveness of statistical misunderstandings, we need to develop and improve statistical literacy which Gal (2002: 1) defines as "the ability to interpret, critically evaluate, and communicate about statistical information and messages." Moreover, we advance that statistical literacy is an important concept for the analysis of the relationship between science and society. In this case, is it necessary to define the concept of statistical literacy or is it adequately covered by the concept of civic scientific literacy?

4. Civic scientific literacy

The concept of scientific literacy is an extension of the concept of literacy, meaning the ability to read and write, to science; thus scientific literacy is the ability to read and write about science. Historically, the conceptualization of scientific literacy was proposed by Shen (1975), who divided it into three categories: practical scientific literacy, civic scientific literacy, and cultural scientific literacy. Practical scientific literacy refers to the level of scientific knowledge used to solve practical problems. Civic scientific literacy refers to the level of understanding of science needed to function as citizens. “Civic science literacy is a cornerstone of informed public policy” (Shen, 1975: 49). Cultural scientific literacy “is motivated by a desire to know something about science as a major human achievement” (Shen, 1975: 49). Since then, most works on the relationship between science and society based on scientific literacy have focused only on civic scientific literacy.

Miller (1983) has defined civic scientific literacy as a three-dimensional construct. Precisely, a scientifically literate citizen needs to have: “(1) a vocabulary of basic scientific constructs sufficient to read competing views in a newspaper or magazine; (2) an understanding of the process or nature of scientific inquiry; and (3) some level of understanding of the impact of science and technology on individuals and on society” (Miller, 1998: 205). This definition has originated many works—both conceptual and empirical—and, after 20 years, a consensus emerges around the first two dimensions and around their empirical measures.

The first dimension of civic scientific literacy is measured through questions about the theoretical and factual findings of science, which are selected from a population of constructs important to efficient citizenship (this population may be approximated by benchmarks for science literacy, as developed in the American Project 2061 (AAAS, 1993)). The measure includes 13 true/false items falling within the physical/natural sciences: items concern, for example, lasers, size of an electron, plate tectonics, radiation, dinosaurs, and antibiotics. Miller (2004: 278) has looked “at four basic constructs as representative of a much larger set of constructs that an individual might need to be able to read and understand a story in the Science Times section.” A series of studies conducted in the United States and Europe since the 1970s, reveals that many citizens do not have a firm grasp of basic scientific facts and concepts.

The second dimension of civic scientific literacy requires that an individual display a minimal understanding of the empirical basis of scientific inquiry. The measurement of this dimension is conducted through two closed-ended items, one of which assesses the respondents’ understanding of experimental logic, the other the understanding of probability, and an open-ended item on what it means to study something scientifically.

The concept of civic scientific literacy includes intrinsically statistical aspects (as statistical knowledge is necessary to read many articles in newspapers or magazines), but it doesn’t mention statistics explicitly. Therefore, the empirical measures don’t cover statistics sufficiently. No place has been found in the first-dimension measures for statistical knowledge, whereas statistics was defined by the American Association for the Advancement of Science (AAAS, 1993) as one key science knowledge necessary for a science-literate population. The second-dimension measures are partially related to statistics, since statistics is more than the scientific experimental method and probability.

5. Discussion

Statistics has penetrated into all aspects of life—from education, work, media, and health to citizenship—and this phenomenon is continuing to evolve. Thus, “statistical evidence and argument are central to decision making on controversial matters having profound social implications” (Sowey, 2003: 89). Most media include statistical references in reports on studies in health, social and demographic trends, economics, etc. The understanding of the statistical elements is an integral part of the understanding of these reports. Therefore, enhancing statistical literacy to increase workers' and consumers' competencies and to develop statistical citizenship is an important issue. Nevertheless, this task is difficult since statistics is associated with what may be characterized as a series of "mis-es"—namely misunderstandings, misperception, mistrust, and misgivings (Wallman, 1993).

In sociology, precisely in *public understanding of science*, the concept of scientific literacy, namely the ability to read and write about science, does not pay considerable attention to statistics, despite the arguments above. In consequence, possible explanations of empirical results found in surveys of attitudes toward science may be missed.

The knowledge-gap hypothesis states that the information flow on a new scientific issue or technology will be not homogeneous across different social strata (Tichenor, Donohue and Olien, 1970): people with higher education tend to acquire this information at a faster rate than those with lower education. Among the explanations provided by Bonfadelli, Dahinden and Leonarz (2002: 122), there is the fact that people with higher education "have better information processing skills." We advance that statistical skills are part of those skills and this suggestion is consistent with the knowledge-gap hypothesis: the more educated have higher levels of statistical literacy than those who have less education, since statistics is introduced in most mathematics curricula around the world at the secondary level and at the university level most majors require that students take an introductory statistics course.

The concept of civic scientific literacy is closely related to the "deficit model" which posits that greater scientific knowledge leads inevitably to greater support for science. A series of empirical studies have concluded that civic scientific literacy, measured as above, is a limited predictor of attitudes toward science: a small positive linear relation in some studies, curvilinear or "chaotic" in other studies (Evans and Durant, 1995; Peters, 2000; Bauer, Petkova and Boyadjieva, 2000; Pardo and Calvo, 2004). Recently, some work has been undertaken to find more social determinants of attitudes toward science (social values, trust in institutions, risk perception, environmental values, etc.). Before leaving aside civic scientific knowledge, we can wonder if other measurements of the concept would have led to the same results, for example a measurement that would have given statistics a place according to its role in modern science- and information-laden societies.

Empirical results have found an increase in ambivalence and "don't know" responses in surveys of attitudes toward science, and that more knowledge brings more polarized or extreme attitudes toward science (Evans and Durant, 1995). On the basis of the mass media effect on the formation of attitudes, the growing emphasis on statistical results in the media may play a part. How to form an opinion about a scientific issue with statistical elements in the media, if one does not understand the statistical elements of the arguments? Since most citizens lack statistical literacy, it is therefore not surprising that ambivalence is increasing and that the better educated (with more statistical skills) are able to develop more firmly held attitudes, more extreme attitudes.

These hypothetical explanations need to be confirmed by empirical research. The introduction of statistical literacy in empirical studies is quite easy since we may ground on the development of the concept in the statistics education field. Statisticians and statistics educators have defined statistical literacy and developed the concept (Gal, 2002; delMas, 2002; Garfield, 2003; Watson and Callingham, 2003). "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" (Wallman, 1993: 1).

The concept of statistical literacy should be added as a fourth element of scientific literacy. Measurement of this fourth element could be based on recent studies on measurement of statistical literacy. For example, we could select items from the international mathematics and science achievements of students, the most well-known being TIMSS and PISA.[3]

Finally, there is a need to promote dialogue on statistical literacy between educators, statisticians, social scientists (especially PUS scientists), science communicators and policymakers to succeed in enhancing citizens' statistical literacy. Resulting actions should be coordinated to gain optimal efficiency. In conclusion, major changes in levels of statistical literacy will be achieved only if it becomes everyone's responsibility: educators, statisticians, journalists, citizens, and also social scientists. Therefore I believe we need a public understanding of statistics.

Notes

1 For example, an American survey shows that only 30 percent of the respondents are able to choose the correct definition of what a 4 percent margin of error means (Annie E. Casey Foundation, 2002).

2 The lie factor is the ratio of the size of an effect shown in the graphic to the size of the effect in the data. Optimal graphics gain a lie factor of 1.

3 For details, see http://timss.bc.edu/ and http://www.pisa.oecd.org/

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