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Students' misconceptions of statistical inference: A review of the empirical evidence from research on statistics education

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Abstract

A solid understanding of *inferential statistics* is of major importance for designing and interpreting empirical results in any scientific discipline. However, students are prone to many misconceptions regarding this topic. This article structurally summarizes and describes these misconceptions by presenting a systematic review of publications that provide empirical evidence of them. This group of publications was found to be dispersed over a wide range of specialized journals and proceedings, and the methodology used in the empirical studies was very diverse. Three research needs rise from this review: (1) further empirical studies that identify the sources and possible solutions for misconceptions in order to complement the abundant theoretical and statistical discussion about them; (2) new insights into effective research designs and methodologies to perform this type of research; and (3) structured and systematic summaries of findings like the one presented here, concerning misconceptions in other areas of statistics, that might be of interest both for educational researchers and teachers of statistics.

Keywords: Statistical inference; Misconceptions; Students; Research review

1. Introduction

Since the early 1970s, there has been an increasing interest in research about people's understanding and performance in probability and statistics. Researchers especially focused on misconceptions and heuristics regarding probability, chance, and randomness (e.g., Kahneman, Slovic, & Tversky, 1982; Konold, 1989, 1991; Nisbett & Ross, 1980; Shaughnessy, 2003). This article reports on a systematic review of the available empirical evidence of students' misconceptions in statistical inference. It constitutes a starting point for educational researchers interested in the relation between misconceptions and the conceptual change theory (e.g., Finch & Cumming, 1998; Guzzetti, Snyder, Glass, & Gamas, 1993; Smith, diSessa, & Roschelle, 1993), or a helpful tool for teachers of statistical inference to become aware of the most common misconceptions that their students may hold (e.g., Batanero, Godino, Vallecillos, & Holmes, 1994; Brewer, 1985; Haller & Krauss, 2002).

In educational research, the term *misconception* is used to refer to several concepts. On the one hand, authors often consider a broad definition of the word, using it to label different concepts such as *preconception*, *misunderstanding*, *misuse*, or *misinterpretation* interchangeably (Smith et al., 1993). On the other hand, misconceptions are sometimes defined in a more restrictive way, as misunderstandings generated during instruction, emphasizing a distinction with

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alternative conceptions resulting from ordinary life and experience (Guzzetti et al., 1993). In this manuscript, a refinement of the first definition is applied, and the term refers to any sort of fallacies, misunderstandings, misuses, or misinterpretations of concepts, provided that they result in a documented systematic pattern of error (Cohen, Smith, Chechile, Burns, & Tsai, 1996).

The interest on *statistical inference* arises from three realities. First, this is a topic of main relevance for the development of research in all empirical sciences in general and psychology and education in particular (Belia, Fidler, Williams, & Cumming, 2005; Krauss & Wassner, 2002). Second, inference receives special attention in statistical courses from almost all scientific areas, where hypotheses tests and confidence intervals are taught to students as *the* methods for evaluating scientific hypotheses (Aberson, Berger, Healy, & Romero, 2003; APA, 2001). Finally, inferential ideas seem to be especially sensitive to be misunderstood and students are often prone to fall into deep misconceptions (Daniel, 1998; Kirk, 2001) because they require students to understand and connect many abstract concepts such as sampling distribution and significance level.

After presenting our methodology of search for this review (Section 2), we provide an overview of the misconceptions mentioned and exemplified in the literature, and describe to what extent and under which conditions they occur, discussing the methodology of the presented group of studies (Section 3). Finally, we conclude with some suggestions for further research (Section 4).

2. Method

We performed a thorough literature exploration in order to bring together publications that report on studies providing *empirical* evidence of *university students*' misconceptions that have been published during the last 15 years (from 1990 to the beginning of 2006). Therefore, studies based on personal experience and anecdotes only or publications oriented to other groups (such as professionals or younger students) were excluded.

Other publications that did not match our inclusion criteria, for instance purely theoretical discussions of misconceptions, will be used here to illustrate original ideas or describe these misconceptions.

We followed four different lines of search: first, as our main source, we surveyed the *Web of Science* (ISI, 2004), *PsycINFO* (APA, 2006), and *ERIC* (IES, 2006) electronic databases. We based our selection of key words[1] on the criteria described above and the main concepts of statistical inference. These concepts were chosen according to the logical structure of statistical inference, which is based on the foundational sampling theory and consists of two main inferential techniques: hypotheses tests and confidence intervals. This structure is as well reflected in the content and order of topics in most handbooks of introductory courses on statistical inference (e.g., Healey, 2005; Moore & McCabe, 2006). These handbooks approach statistical inference by firstly introducing sampling processes and related concepts and properties, focusing on the concepts of population, sample, point estimation by means of sample statistics (e.g., the sample mean), sample and sampling distributions, and practical approximations (e.g., central limit theorem). Next, students learn how to construct and understand confidence intervals for the estimation of different parameters as well as to perform hypotheses tests. We will use this structure to present the results of our review in this manuscript (see Section 3).

Second, after searching in electronic databases, we complemented our list of references by in depth scrutinizing the main forums for research on statistics education:

- Journal of Statistics Education, all available articles: from Volume 1 (July 1993) to Volume 13 (November 2005).
- Statistics Education Research Journal, all available articles: from Volume 1 (May 2002) to Volume 4 (November 2005).
- Proceedings from the 5th (1998) and 6th (2002) International Conferences on Teaching Statistics (ICOTS).

Next, we started a third line of search, tracking down all references cited in the results of the previous two searches.

[1] The following combination of keywords was used: (*Misconception* OR *error* OR *misuse* OR *misinterpretation* OR *misunderstanding* OR *fallacy*) AND (*inference* OR *sampling* OR *normal* OR *confidence* OR *interval* OR *test* OR *level* OR *p-value*) AND *student* AND (*course* OR *college* OR *university*).