1 Introduction

Information is the fuel of the knowledge society in which we live.
Johan van Benthem

The present study is a sequel to design research in statistics education carried out by Cobb, McClain, Gravemeijer, and their team in Nashville, TN, USA. The research presented in this thesis is also part of a larger research project on the role of IT in secondary mathematics education.[1] In the remainder of this introductory chapter we discuss the notions of the title *Design research in statistics education: on symbolizing and computer tools,* and identify the purpose of the research.

1.1 Statistics education

Statistics is seen as a science of variability and as a way to deal with the uncertainty that surrounds us in our daily life, in the workplace, and in science (Kendall, 1968; Moore, 1997). In particular, statistics is used to describe and predict phenomena that require collections of measurements. But what are the skills essential to the navigation of today's technological and information-laden society? Statistical literacy is one of those skills. Gal (2002) characterizes it as the ability to interpret, critically evaluate, and communicate about statistical information and messages. We give three instances to exemplify how citizens of modern society need at least some statistical literacy.

1 Many newspapers present graphs or data on the front page. Apparently, citizens are expected to understand and appreciate such condensed information; it is not just the educated who are confronted with statistical information. Research in statistics education, however, shows that graphs are difficult to interpret for most people:

> The increasingly widespread use of graphs in advertising and the news media for communication and persuasion seems to be based on an assumption, widely contradicted by research evidence in mathematics and science education, that graphs are transparent in communicating their meaning. (Ainley, 2000, p. 365)

   It could also be that newspapers attempt to create a reliable or scientific impression.

2 More and more large companies have a policy of teaching almost all employees some basic statistics. This is often part of a quality control method; for instance,

1. Among the publications of the other project members are Drijvers (2003), Doorman (in press), Hoek, Seegers, & Gravemeijer (in press), and Pijls, Dekker, and Van Hout-Wolters (2003).

Six Sigma aims to increase profitability by controlling variation in production processes (e.g. Pyzdek, 2001). The basic idea of statistical process control is that variation and the chance of mistakes should be minimized and that to achieve that, every employee should be familiar with variation, usually measured by the standard deviation, around a target value, usually the mean (Descamps, Janssens, & Vanlangendonck, 2001). This makes statistics an instrument for economic success.

3 In almost every political and economic decision, at least some statistical information is used. Fishermen, for instance, negotiate with the government and perhaps environmental groups about fish quotas, which are based on data and statistical models (Van Densen, 2001). This makes statistics a language of power.

If we want to provide all students some basic statistical baggage, we need to teach statistical data analysis to school-aged children. Statistical literacy, however, is not an achievement that is readily established: the growing body of research in this area shows how much effort it takes to teach and learn statistical reasoning, thinking, and literacy (Garfield & Ahlgren, 1988; Shaughnessy, Garfield, & Greer, 1996). Students need to master difficult concepts and use complicated graphs, and teachers often lack the statistical background to help students do so (Makar & Confrey, in press; Mickelson & Heaton, in press). This implies that students need early exposure to statistical data analysis and that we need to know more about how to support them.

Besides societal need, there are also theoretical reasons to do research in statistics education. It is a useful field to investigate the role of representations in learning, because graphs are key tools for statistical reasoning (Section 1.3). Statistics education is also a suitable field for investigating the role of the computer in the classroom, because the computer is almost indispensable in performing genuine data analysis due to the large amount of data and laborious graphing (Section 1.4).

In some countries such as the United States of America and Australia, students already learn some statistics when they are about ten years old, explaining why most available research at the middle school age comes from these countries (ACE, 1991; NCTM, 1989, 2000). In the Netherlands, students first encounter descriptive statistics when they are about 13 years old, and hardly any Dutch research into statistics education with younger students has been carried out.

It is clear from the growing need for statistical literacy and the relatively small amount of research and experience with 10 to 14-year-old students that we need an instruction theory for early statistics education. In short, an instruction theory for a specific domain is a theory of how students can be supported in learning that domain. It entails knowledge about students' statistical intuitions, the key concepts of statistics, the type of reasoning and thinking that is possible for specific age groups, and supportive instructional activities embedded in a longitudinal learning trajectory.

The purpose of the present research is therefore

to contribute to an empirically grounded instruction theory for early statistics education.

When we write ‘statistics’, we mean descriptive statistics and exploratory data analysis, not inferential statistics. In Chapter 2, we set out our points of departure and summarize the research literature relevant to our study, in particular that of Cobb, McClain, and Gravemeijer, which leads to the research questions of the present study.

1.2 Design research

One way to develop an instruction theory is by conducting design research. The strength of design research (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003) or developmental research (Freudenthal, 1991; Gravemeijer, 1994, 1998) is that it can yield an instruction theory that is both theory-driven and empirically based. A design research cycle typically consists of three phases:

1 preparation and design;
2 teaching experiment;
3 retrospective analysis.

The methodology of design research is described in more detail in Chapter 3. In that chapter we also present an overview of the teaching experiments we carried out in Dutch seventh and eighth-grade classes (age 11-13). The preparation phase consists of a historical study (Chapter 4) and a so-called didactical phenomenology (Chapter 5). The teaching experiments in grade 7 are described in Chapters 6 and 7, and the teaching experiment in grade 8 in Chapter 9. Retrospective analyses are presented in Chapters 6 to 9.

1.3 Symbolizing

To investigate the role of graphical representations in learning statistics we use semiotics, the science of signs and meaning. Semiotically seen, a graph is a sign, and a sign is defined as something that stands for something else for someone (Peirce, NEM). In our context, the first ‘something’ is mostly an inscription on paper or computer screen and the second ‘something’ is a mental construction, ideally a mathematical or statistical object. By ‘someone’ we mostly mean a student, but it could also be ‘the’ community of statisticians. A symbol is a sign for which the representational relation is conventional or arbitrary, and not based on likeness for instance (Peirce, NEM). A diagram is a sign representing relations. In statistics education, we

are mainly interested in diagrams and symbols.
At the end of the nineteenth century, the non-fixed relationship of a sign and its object was introduced by the philosophy of language and has been widely accepted ever since. In particular, it is acknowledged that a sign is always interpreted as referring to something else within a social context. For a statistician, for example, a sketch similar to Figure 1.1 signifies a normal distribution, but a student who does not know this distribution as a statistical object may interpret it as an image of a mountain. This indicates a fundamental learning problem: symbols in mathematics and statistics refer to objects that students still need to construct. This problem can supposedly be overcome if students start with simple symbols and meanings they attribute to them and gradually develop more sophisticated symbols and meanings. It is assumed that the process of symbolizing (making, using, and adjusting symbols) and the process of constructing meaning of such symbols co-evolve (Meira, 1995). How this co-evolvement proceeds is the theme of Chapters 8 and 9.

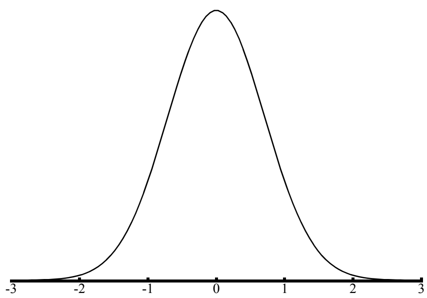

Figure 1.1: Graph symbolizing the normal distribution

1.4 Computer tools

Computer tools allow users to dynamically interact with large data sets and to explore different representations in a way that is impossible by hand. However, computer tools can also distract students' attention to the tools themselves instead of mediating effectively between the learner and what is to be learned (Noss & Hoyles, 1996). As we establish in Section 2.2, students with hardly any statistical background need special educational software to *learn* statistics. We are therefore interested in the question of how such educational computer tools could be used to support students' learning. In the present study we used the Minitools (Cobb, Gravemeijer, Bowers, & Doorman, 1997) that were designed for the Nashville research. The Minitools are three simple applets with one type of plot for each applet, which we have translated and revised. Minitool 1 offers a value-bar graph, Minitool 2 a stacked dot plot, and Minitool 3 a scatterplot (see Section 2.3). In the present study, students only used Minitools 1 and 2.