DESIGN PRINCIPLES, REALIZATIONS AND USES OF SOFTWARE SUPPORTING THE LEARNING AND THE DOING OF STATISTICS – A REFLECTION ON DEVELOPMENTS SINCE THE LATE 1990S

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Starting from my 1997 paper on "Software for learning and for doing statistics" the presentation will analyze developments in the years since then, including the emergence of software tools such as TinkerPlots and Fathom, which are close to the requirements developed in 1997 and which have been the object of many studies of students using these tools for gaining statistical knowledge and practice. More general tools such as EXCEL, the TI Nspire and GeoGebra have also been including more features to support the learning of statistics. Based on these analyses and the currently available technologies (including web applications such as CODAP and several R-based environments) the 1997 requirements will be critically evaluated and updated with a view to future developments.

INTRODUCTION

Discussing software under the perspective of how it supports both the learning and the doing of statistics has recently been resumed by Amelia McNamara (2015). She kindly refers to Biehler (1997), where this was discussed under certain historical circumstances. That paper was based on several assumptions and visions about what should be the content and working style in probability and statistics education. Contemporary changes in the field of statistics such as the emergence of Exploratory Data Analysis (EDA, Tukey 1977) and the growth of computational statistics with its heavy use of simulations were reflected in the paper (Efron, 1982). EDA puts the interactive, heavily graphical exploration in its focus and works with multivariate data sets. Probability modelling became more applied. Computational tools allowed to overcome the simple assumptions with were trackable in an analytical way. More complex and realistic models can be studied through computational modelling. Models can be related to real data so that models can be validated and updated in a next step of a modelling cycle.

If we want to implement these new practices in introductory education, we need adequate computational tools. On the other hand, computational technology has the potential to support active learning by interactive visualizations, by providing environments for experimentation with methods and by use simulations that make probability experiential. Several programs were around – that we would call applets today – and the question was: Can we imagine a tool for doing statistics that at the same can support the creation of interactive applets that support learning. Based on this content-related vision the problem was, which features should a computational tool have so that it can support learning and performing these new practices in statistics and probability even in introductory statistics and probability courses at high school and at the entrance level of universities. Within the context of statistics itself, different kinds of tools had been developed aiming at supporting the new statistical practices since the 1980s. On the one hand, the programming language S had already been developed (Becker, Chambers, and Wilks 1988), on the other hand Data Desk was the new prototypical tool for doing statistics with a graphical user interface (Velleman 1989). S has now been replaced by R, which has become the standard tool for doing statistics and doing research on statistical methods. From the currently available tools, JMP is similar in interaction style to Data Desk, while Data Desk is still available. Both tools, JMP and R are of course much more advanced in terms of the statistical and graphical methods they incorporate and the elaboration of the user interface. Both these recent tools have educational uses, see e.g. Kraft (2016) for JMP and Gould et al. (2016) for R. The educational uses were partly done with adaptations of the tools.

However, in 1997 the available tools did not fulfil several requirements from the perspective of statistics education, such as supporting the experimentation with statistical methods and modelling with simple probability models as needed in introductory education. The programs Tinkerplots (http://www.tinkerplots.com) and Fathom (https://fathom.concord.org), which were

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developed later in the 2000s fulfil many of the requirements specified in Biehler (1997) and are widely used in research and development projects in statistics education (Biehler et al. 2013). A further step ahead is the recently developed CODAP tool (https://codap.concord.org), which integrates features of Tinkerplots and Fathom and adds some important features concerning hierarchical data representations and representations of geographical data. However, CODAP has not yet the full functionality of Tinkerplots and Fathom. A basic advantage of CODAP as compared to Fathom and Tinkerplots is that it is web based and offered free of cost.

In many experimental settings, these tools were successfully used (Biehler et al., 2013). Although Tinkerplots was mainly designed for primary and middle school students, it was also successfully used in college education (Zieffler et al, 2013) or in pre-service teacher education (Biehler, Frischemeier, Podworny 2017 and Frischemeier 2016). A broad success of Tinkerplots and Fathom in practice was limited however due to several reasons. A major reason is that the new vision of statistics and probability and its teaching that is underlying these tools has not yet become a mainstream at high school and college level in any country. Moreover, on both levels there are competing tools. At high school, spreadsheets, graphic calculators and general tools such as GeoGebra are often preferred because they cannot only be used in statistics and probability but in other parts of the mathematics curriculum as well. These tools cannot support the vision of modern computational statistics and probability but many instructors do – unfortunately - not miss these features or feel that the learning time devoted to probability and statistics is too small for such an approach. At college level, Tinkerplots and Fathom compete with the professional tools in statistics such as R, JMP, SPSS and others, depending on the respective faculty or course. Investing time into learning specifically designed educational tools seems not to be a reasonable choice. Starting directly with the tool that will be used later is preferred. Moreover, there are recent changes in statistics in the direction of data science (Ridgway 2015, Cleveland 2001). These changes create new requirements for adequate tools (McNamara, 2015). Programming capabilities and the need of documenting data analysis processes guarantee the reproducibility favor of R or even Python as a programming environment. These tools are also able to cope with really big data sets and with the design, implementation and use of modern algorithms of data science, whereas tools such as Fathom, Tinkerplots and CODAP are not.

PUTTING TINKERPLOTS AND FATHOM INTO PERSPECTIVE

Based on this background, the presentation will discuss the following points

1. What are the unique design features of Fathom and Tinkerplots that make them tools both for learning and for doing statistics?
2. Which type of practices in probability and statistics do they support well and not so well? Where are their limitations?
3. What are constraints and affordances of the tools with regard to supporting novices entering into the practice of statistical data analysis and probability modelling?
4. What are favorable and less favorable conditions for the use of these programs in educational contexts?

A NEW VISION FOR INTRODUCTORY EDUCATION IN DATA SCIENCE, STATISTICS AND PROBABILITY WITH ADEQUATE TOOLS

Based on experiences in recent projects, finally, a vision will briefly be sketched regarding the further development of tools and of using these tools in different educational contexts. I will briefly report on Tinkerplots' uses in primary and lower secondary education and then sketch how we consider the use of tools in a pilot data science course we are developing for 12graders in Germany. We consciously plan to introduce the students into the data analysis facets of data science by using Fathom and CODAP first and then move to Python while using Jupyter notebooks (http://jupyter.org). The solution cannot be to find one tool that grows continuously with the growth of the user. It is necessary to use several tools but consciously support the transition of the discontinuities and gaps that exist between these tools and the respective statistical practices.

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