Some Potentials of the R-Project Environment for Teachers' and Students' Education in Mathematics, Algorithms' Programming and Dynamic Website Development

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Abstract: Mathematics and information technology play a major role in sustaining the competiveness of modern economies. Mathematics is a versatile and precise language that is used to formalize and deal with problems and to analyse the huge amount of data that is now being collected. Information technology, with the support of a numerical/statistical programming environment, is the platform that makes it possible to collect, store, process and analyse data. The presentation of data, e.g., on the web or in an app, is also important. In a wider context this leads to dynamic websites programming which may be developed within a corresponding web development framework. A sound understanding of these three aspects—mathematics, a numerical/statistical programming environment, and web development—is crucial. In this paper, we propose an integrated approach, based on the R-Project environment, to incorporating these fields in teachers' and students' education.

Introduction

In education, the STEM subjects are considered as crucial to maintaining the competiveness of modern economies. Mathematics and information technology in particular play pivotal roles. Mathematics, as a context-free method, is widely applied to formalize and solve real-life challenges, while information technology impacts on practically every area of life, whether it may be at a personal or company level or on whole economies.

Mathematics and information technology reinforce each other. Information technology without mathematics would not be possible and (applied) mathematics benefits significantly from information technology. Computational-intensive mathematical models as used in climatology research, for example, would not be possible without (super-)computers. The same applies to the task of analysing the huge amounts of customer data that companies collect. Information technology is the enabler to collect these data and without mathematics they could not be analysed. Mathematics and information technology, which are inextricably combined, are the key drivers behind scientific and economic progress.

It is also vital that the results obtained by analyses be presented in an easily accessible way. This can be done through the use of dynamic websites. However, the importance of dynamic websites goes beyond presentation of the results of mathematical analysis. Dynamic websites pervade in the Internet, so understanding how they work provides important insights as to how the Internet works. These three aspects — (1) mathematics, (2) programming, here in particular supported by a numerical/statistical programming environment, and (3) web development — address some of the most important recent trends in technology. A sound understanding of these fields is critical in education and have been also already addressed in literature, e.g., by Niess (2005) or Ruthven & Hennessy (2002).

The objective of our paper, therefore, is to contribute to this discussion by proposing an integrated approach, based on the R-Project environment, as to how these fields can be incorporated in teachers' as well as in students' education. The paper is organized as follows. In the next section, we discuss numerical computing environments and explain why we selected R for our project. In the subsequent section, we show how R supports education in mathematics, programming and website development. The paper concludes with a summary.

Some Notes on the R-Project Environment

Numerical Computing Environments

Numerical computing environments are software packages that are designed to support any kind of numerical analyses, e.g., in engineering, science, economics and other areas. The major numerical computing environments include R-Project, MATLAB and Mathematica.

In 1993, the R-Project environment was introduced by the University of Auckland as a free alternative to the statistical programming language S (Ihaka, 1993). Like S, it was initially focused on statistics, but it has since become one of the leading environments for any kind of data analysis, including statistics, data mining and machine learning. It also covers several other areas in mathematics, like operations research and linear algebra. In the current TIOBE Index (tiobe.com/tiobe-index/) it is ranked #15, making it the leading special purpose programming language in the index. R is well accepted in academia and industry (Vance, 2009) and supported by major international tech-giants like Microsoft (Olavsrud, 2015) and Oracle (Oracle Inc., 2017).

One of its commercial competitors, MATLAB (mathworks.com), is presently ranked #17 on the TIOBE Index, closely behind R. While MATLAB is mainly used in industry, in particular in engineering and science, another competitor, Mathematica (wolfram.com) is well represented in educational institutions. Besides its rich library of predefined mathematical functions and easy ways to deal with data and sophisticated graphics tools, Mathematica‘s main advantage is its symbolic computation functionality. It can, for example, symbolically integrate or differentiate functions. These features make it a very useful environment to support mathematics education. Furthermore, its console-based approach fosters the programming of algorithms and its export functionalities encourage the development of webpages. Besides these commercial alternatives to R, various free and/or open source numerical computing environments are available, including GNU Octave (gnu.org/software/octave) and Scilab (scilab.org/). Both claim to be more or less compatible to MATLAB.

Selection of the Numerical Computing Environment for Educational Purposes

Considering its strong position in engineering, science and industry, MATLAB and its free derivatives would be excellent choices for education in engineering and science. MATLAB would also be a good environment for any kind of education that is related to simulation and data analysis, as is often employed in economics, marketing and other fields. However, we think that Mathematica is more suitable than MATLAB to support general mathematics education of teachers and students. In particular its symbolic computation functionality puts it ahead of MATLAB. Its suitability for mathematics education has given it a leading role in this sector. For example, Mathematica has been successfully used in the mathematics education of computer science students at Munich University of Applied Sciences for several years.

We consider R as a strong alternative Mathematica in supporting the education of teachers and students in mathematics, programming and web design. Mathematica, like MATLAB has a distinct advantage over R in regards to its symbolic computation functionality. Since it is a commercial product Mathematica also has more structures and is better integrated than a community project like R. This is not only related to supporting documentation but also to the integrated functions. In R everybody can distribute a package, hence the nomenclatures of the functions vary and may not even be unique, while functions may be implemented more than once or the content of packages can be heterogeneous, since they address the special needs of their authors.

It is beyond the scope of this paper to discuss the quality of software in detail. However, it should be noted that the quality of R packages may vary. They are only formally checked in the uploading process; the correctness of the algorithms is not checked. Due to the large number of packages and their often very specific areas of application we do not think that the community mechanisms in open source projects can be relied on to check the codes for all packages., The packages, therefore should be carefully selected and possibly limited to well accepted and frequently used packages and ones submitted by trustworthy sources (e.g., packages contributed by academics from respected universities).

One of the goals of our project has been to facilitate access to the platform, (i.e., the operating system, the numerical environment runs on and software licensing costs). Both Mathematica and R run on all major operating systems (Apple's OS, Linux and Windows), while Mathematica has also launched a cloud based version that runs in web-browser. Both environments are practically platform independent. However, they are significantly different when it comes to licensing costs. Mathematica is a commercial product while R is an environment that can be downloaded for free. The educational sector faces budget pressures in almost every country. In Germany, for example, basic funding per student decreased in 12 of 16 states from 2004 to 2015; in one state the funding remained unchanged and only three states increased their basic funding per student over this time period (Kaufmann, 2016). In Australia, the government is proposing new university funding legislation that would lead to budget cuts at universities (Bagshaw, 2017; Karp, 2017). Further, there are many countries where educational budgets are significantly lower or even virtually non-existent. It should also be possible for students, outside of university or school laboratories, to legally download and run such an environment on student/teacher's personal hardware. To restrict the cost of accessing a numerical computing environment to the purchase of hardware, we excluded Mathematica and selected R-Project as the platform to support mathematics education and programming and web-site development.

Accessing and Using R

R can be downloaded from the project website at r-project.org for all major operating systems. It has a built in console. Alternatively, there are several third-party IDEs available, with RStudio (rstudio.org) probably the most popular (see Figure 1 for a screenshot for RStudio IDE). RStudio integrates a console, an editor and windows, e.g., for graphics. RStudio also supports the download of packages and the import of datasets in several formats. R has a built-in help function but there are also plenty of resources, ranging from books, webpages and blogs and forums on R. They include, for instance, Matloff (2011), Murrell (2011), Teetor (2011) or Venables et al. (2017).

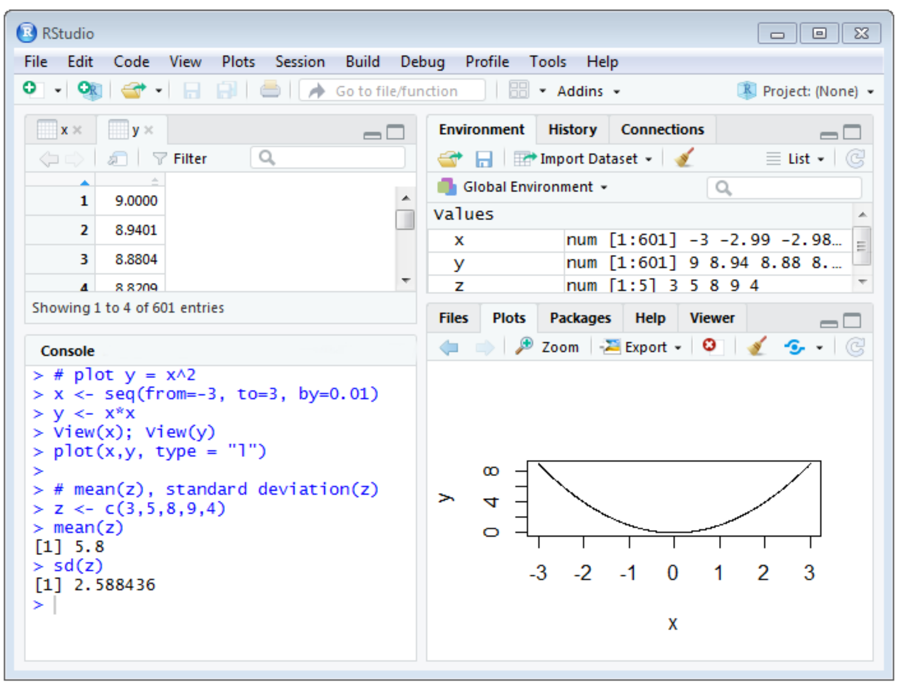

Figure 1: RStudio IDE (rstudio.com)

Case Study based on R-Project

Framework of the Project

A joint team from the Faculty of Education and Arts at Australian Catholic University and the Department of Computer Science and Mathematics at Munich University of Applied Sciences, Germany has launched a project to evaluate the possibility of integrating R in teachers' and students' education. Australian Catholic University members have mainly covered pedagogical aspects related to students' and teachers' education while the Munich University of Applied Sciences members have been mainly responsible for the technological side of the project. R-Project is already successfully used in information systems at Munich University of Applied Sciences, e.g., in the courses data analysis and decision theory in the master program and a project-based course in the bachelor program.

An objective of the cooperation between Australian Catholic University and Munich University of Applied Sciences is to investigate how we can leverage on our expertise in education on the one hand and computer science and information systems on the other hand. Based on the experience we have gained in using R in teaching already we have started to transfer it to teachers' education in mathematics and (algorithmic) programming. In a case study, we also set up a project to evaluate the possibility of using R packages to develop web design development. The objectives are twofold. First, the project members are trained in the development of dynamic websites. Second, the obtained website can be used to train students in mathematics.

Dimensions of the Framework

In the following paragraphs we discuss the three dimensions (mathematics, programming and website development) as defined above in more detail. As we will see, mathematics and programming partly overlap. This also applies to programming and web site development, since web site development is basically a programming task. However, we refer here to programming as programming of (mathematical) algorithms to distinguish it from website programming. Besides these dimensions we also address further benefits of using R-Project in teachers' education in the context of website programming.

Mathematics Education

R has its origin in statistical analysis. However, it also covers other areas in mathematics. In mathematics education we distinguish between to aspects. The first area is applied mathematics and the second, we call algorithmic mathematics. Since R provides a wide range of mathematical functions, they can be used immediately and applied to mathematical tasks. A very simple example would be calculating the mean and the standard deviation of the numbers 3, 5, 8, 9, 4 which can be easily performed in R's console as follows:

```
x <- c(3,5,8,9,4)
mean(x)
sd(x)
```

R also provides the possibility to program functions from scratch, which leading to a better understanding. The mean could be implemented as follows using R's sum and length functions. This implementation reflexes the mathematical definition of the mean and may provide the learner with a better understanding of the function:

```
x <- c(3,5,8,9,4)
sum(x)/length(x)
```

Education in Programming

We could also regard such a task as the one above as a programming matter and less mathematics issue. Then the sum-function would be implemented from scratch leading to:

```
x <- c(3,5,8,9,4)
sumData <- 0
lengthData <- length(x)
for(i in 1:lengthData){
    sumData <- sumData + x[i]
```

```
}
sumData/lengthData
```

Note, from a R-programmer's perspective this code is 'bad'. However our focus here is not on comfortable R functionalities but on the algorithm structure of calculating a sum.

Website Development

R is comfortable exporting function to a wide range of formats, including MS Word and LaTeX - see for example the Sweave (Leisch, 2002) and the Markdown (RStudio, 2014) packages. The Shiny package of R (Chang, 2017, project webpage: https://shiny.rstudio.com) supports the development of dynamic websites. Impressive examples can be found on the homepage of the Shiny project. In our project we developed websites to support mathematical education based on Shiny. An example for a mobile webpage is given in Figure 2. Note, that the Shiny package is R specific and therefore is not representative of the technologies that are used in major website developments. However, it provides good insights in the development of dynamic websites and, most importantly, smoothly integrates into our framework of mathematical and programming education. A further advantage of website programming is that, as our example shows, the generated websites can be used as training applications to support education in mathematics. These websites are similar to math-apps like Mathway (mathway.com), MATH 42 (math-42.com) or MalMath (malmath.com). The R environment could become a community–based free alternative to these apps and thus address the special needs of teachers and students in mathematics and programming education.

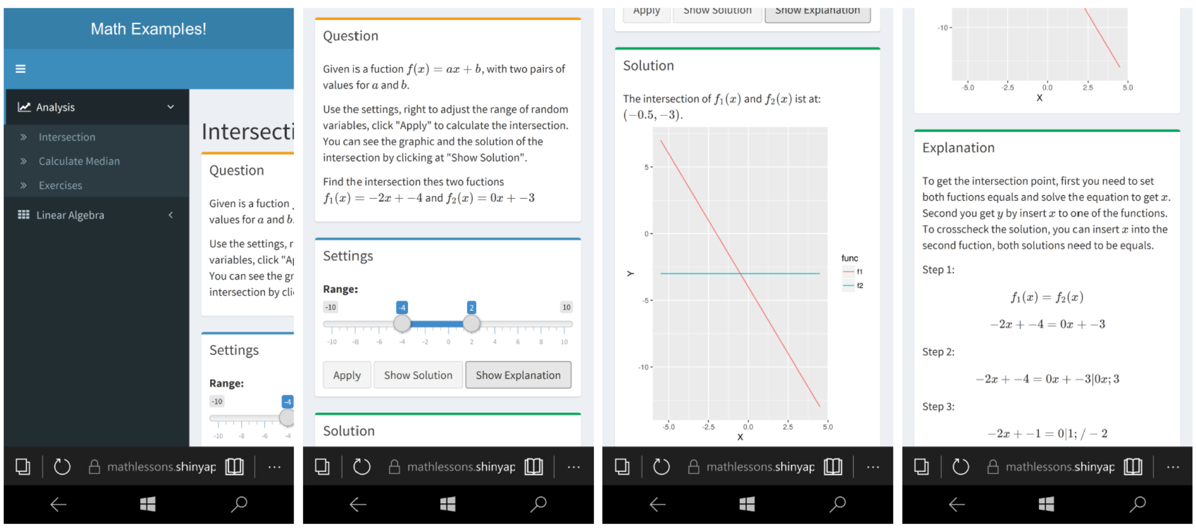

Figure 2: Mathematics Example for a Webpage on a Mobile

Conclusion

In this paper we discussed whether the R-Project could be used to support the education of teachers and students in mathematics, programming and dynamic website design, thus addressing some of the most challenging and urgent needs of today. To back our proposal we presented a prototype application. Due to the current momentum behind R in academia as well as in industry, we think that it is a very suitable environment for this purpose. Besides its powerful functionality and wide range of already implemented mathematical algorithms, it also supports the graphical representation and supports the export of the obtained results into a wide range of formats.

Another crucial advantage of R is that, since it is free, the financial entry barriers are very low and the project is independent of present and future budget constraints. This applies not only to so-called developed countries but it would also strengthen education in developing countries which often suffer from much tighter financial constraints than mature economies. We believe it is an ideal environment that can holistically address crucial needs in today's education of teachers and students.

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