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R PROJECT APPLIED TO THE TEACHING OF NUMERICAL METHODS

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Abstract: This article analyzes the potential of the R Project as a tool for teaching numerical methods in engineering degrees. Traditionally, this content is taught using proprietary software, which limits student access outside the classroom and reduces the possibilities for reproducibility and integration with data analysis. R, being a free and open-source environment, allows the implementation of classic numerical method algorithms (such as interpolation, numerical integration, solving differential equations, and linear equation systems) while also facilitating graphical visualization and experimentation with different parameters. Based on a review of specialized literature and various teaching experiences, a didactic design is proposed that integrates the use of R for the development of activities focused on problem solving, reproducible documentation, and written reflection on the results obtained. The theoretical findings suggest that the use of R in this context contributes not only to the conceptual understanding of numerical methods, but also to the strengthening of cross-cutting skills such as programming, critical data analysis, and scientific communication. It is concluded that the R Project represents an accessible and pedagogically sound alternative for modernizing the teaching of numerical methods, and future lines of empirical research are proposed to evaluate its impact on student performance and attitudes toward applied mathematics and computing.

Keywords: R Project, numerical methods, learning, higher education.

INTRODUCTION

Numerical methods courses occupy a central place in the training of engineers, as they provide tools for solving modeling problems that do not admit a closed analytical solution and that appear recurrently in professional practice (e.g., nonlinear equations, numerical integration and derivation, systems of differential equations, and optimization) (Chapra & Canale, 2015). However, several authors point out that these courses are often perceived as highly abstract, with a predominance of activities focused on manual calculation and limited integration of experimental or simulation experiences that allow algorithms to be connected to real-world problems (Triana & Ferro, 2021). This gap between the theoretical approach and the use of computational tools can translate into difficulties in developing modeling skills, algorithmic thinking, and critical analysis of numerical results.

In this context, the use of specialized software has established itself as a key resource for teaching numerical methods. Traditionally, proprietary platforms such as MATLAB have dominated this space, but their licensing costs can limit sustained adoption in institutions with budget constraints (Chapra, 2018). In response to this, the R language is presented as a free and open-source alternative, developed as a GNU project and available for multiple operating systems, which integrates programming, numerical analysis, statistics, and graphical visualization in a single environment (R Core Team, 2025). From the perspective of university teaching, these characteristics favor both the reproducibility of numerical experiments and the creation of teaching materials that students can install and reuse without licensing restrictions.

The specialized literature shows that R has been successfully used for the development of teaching activities in mathematics and statistics. Cheang (2004), for example, explores the use of R as a free substitute for computer algebra systems in numerical analysis courses, highlighting its power to implement classical algorithms such as the bisection method and to visualize iterations and approximation errors in a flexible manner. In secondary education, Briz-Redón and Serrano-Aroca (2018) show that working with algebraic content through programming in R promotes logical reasoning, experimentation with different parameters, and understanding of mathematical concepts that are difficult to address with pen and paper alone. More recently, Parra, Sanjuán, Robustillo, and Pizarro (2023) document experiences in which R has established itself as a tool that links teaching and research, allowing for the design of activities ranging from simulation to the analysis of real data in different university subjects.

Despite these advances, there is still relatively little literature that systematically describes the design, implementation, and evaluation of teaching experiences where R is specifically used as the main platform for teaching numerical methods in engineering degrees. Bloomfield (2014) shows the potential of R to solve a wide range of numerical problems—linear systems, differential equations, optimization, spectral analysis in scientific and engineering contexts—but his approach is fundamentally technical and does not focus on the pedagogical analysis of its integration into the classroom. Complementarily, Triana and Ferro (2021) illustrate how working with image processing and finite difference problems can be used as a problem-based learning strategy in numerical analysis courses, although without delving into the use of R as the main programming environment.

Within this framework, this article aims to analyze the use of the R Project as a central resource for teaching numerical methods in university education. In particular, it seeks to describe the design of activities that integrate the implementation of classical numerical method algorithms in R, the visualization of results, and the resolution of contextualized engineering problems, as well as to assess their impact on the development of modeling skills, computational thinking, and conceptual understanding. This analysis aims to contribute to the discussion on the incorporation of free software in the teaching of numerical methods, offering evidence and guidance for teachers who wish to move from traditional approaches to more active, experimental, and reproducible proposals supported by R.

Advantages of using the R Project in teaching numerical methods

The use of R Project in teaching numerical methods offers a number of pedagogical, technical, and economic advantages that make it an attractive alternative to other proprietary environments. First, R is free and open-source software, which allows any student to install it on their own computer without licensing costs. This encourages continued learning outside the classroom, independent repetition of exercises, and exploration of additional problems without relying on institutional laboratories or temporary licenses.

Second, R integrates programming, numerical analysis, statistics, and graphical

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visualization into a single environment. This integration is especially valuable in numerical methods courses, as it allows students to move from the mathematical formulation of a problem to its computational implementation and the interpretation of results in the form of tables or graphs, all within the same platform. Students can observe, for example, how truncation error evolves when varying the step size in a numerical integration method or how different iterations of a method for solving nonlinear equations converge.

Another important advantage is reproducibility. Through tools such as scripts in R, it is possible to transparently record the steps taken in solving a numerical problem: definition of functions, parameters used, number of iterations, convergence criteria, and visualizations generated. This traceability makes it easier for teachers and students themselves to review their work, identify programming or approach errors, and gradually improve the quality of their procedures.

In addition, the use of the R Project encourages the development of cross-cutting skills that are relevant to engineering education. Constant work with code improves algorithmic thinking and the ability to break down complex problems into simpler steps. Critical analysis of numerical results and their communication through reproducible reports strengthen argumentation, scientific writing, and evidence- stallation skills. In this way, the numerical methods course ceases to be solely a space for applying formulas and becomes a laboratory for modeling, analysis, and technical communication.

Finally, R has a large community of users and developers who contribute specialized packages for different fields of application. This allows the content of the numerical methods course to be connected to real problems in engineering, natural sciences, economics, or social sciences. For students, seeing that the same commands and functions they use in class are also used in current research and professional contexts is motivating and reinforces the perception of the usefulness of the content covered.

Examples of the application of R Project in the teaching of numerical methods

Below are some examples of how R Project can be used in teaching numerical methods in university-level courses, especially in engineering programs:

- Implementation of classical algorithms: Students can use R Project to program and implement classical numerical method algorithms, such as the bisection method, the Newton-Raphson method, fixed--point methods, or the Jacobi and Gauss-Seidel methods for systems of linear equations. Using these codes, students can experiment with different initial conditions, tolerances, and maximum numbers of iterations to analyze the convergence or divergence of the procedures. These types of activities allow them to relate the theory seen in class to the actual behavior of the algorithms when applied.
- Simulation and analysis of numerical error: R Project can also be used to design simulations that help understand the nature of numerical error and its propagation. For example, the teacher can ask

students to compare known analytical solutions with those obtained using different numerical integration methods (trapezoidal rule, Simpson's rule, multiple-step integrators, etc.) for different step sizes. By graphing the error as a function of step size, students observe how the order of the method, stability, and accuracy are related, contributing to a deeper understanding of the concepts of truncation error and rounding error.

- Modeling projects and real-world problem solving: Another application involves developing integrative projects in which students model real-world problems and solve them using numerical methods implemented in R. For example, problems involving heat transfer, population growth, fluid dynamics, or mechanical vibrations that give rise to ordinary differential equations can be posed. Students formulate the model, select the most appropriate numerical method (Euler methods, Runge-Kutta methods, implicit schemes, etc.), implement the algorithm in R, and analyze the results using graphs and tables. Finally, they present their conclusions in structured reports, which reinforces both their understanding of the methods and their scientific communication skills.

Case studies:

a) Significant Figures Applied in R-Project

In R, when working with numerical calculations, significant digits affect how results are printed and stored. R displays numbers with a certain number of significant digits by default, but this can be controlled using functions such as signif().

Code in R

```
number <- 123.456789123
significant_number <- signif(number, 4)
cat("Number with 4 significant digits: ", significant_number, "\n")
significant_number_2 <- signif(number, 2)
cat("Number with 2 significant digits: ", significant_number_2, "\n")
```

In numerical methods, such as approximations, integration, or equation solutions, controlling significant digits is essential for several reasons:

- Accuracy. It prevents cumulative errors in calculations. If you use more or fewer digits than necessary, you could lose information or introduce large errors.
- Proper rounding. It minimizes rounding errors when representing long numbers or results of successive operations.
- Correct interpretation. It allows you to communicate results in a way that reflects the actual accuracy of your data and does not exaggerate its precision.
- Efficiency. It helps optimize computing resources by not storing or processing more digits than are actually necessary.

b) Precision Applied in R-Project

This refers to the closeness of repeated measurements of the same object or quantity under the same conditions. High precision means that the measurements are consistent and have little dispersion. It does not imply that they are close to the true value. More briefly and concisely, precision refers to the dispersion of the set of values obtained from repeated measurements of a magnitude. The smaller the dispersion, the greater the precision. A common measure of variability is the standard deviation of the measurements, and precision can be estimated as a function of it.

Code in R

```
f <- function(x) x^2 - 2
df <- function(x) 2*x
newton_raphson <- function(x0, tol = 1e-6, max_iter = 100) {
 iter <- 0
 x <- x0
 while (abs(f(x)) > tol && iter < max_iter) {
   x <- x - f(x) / df(x)
print(x)
   iter <- iter + 1
 }
 return(x)
}
results <- c(newton_raphson(1.5), newton_raphson(1.6), newton_raphson(2))
cat("Results of the Newton-Raphson method iterations: ", results, "\n")
precision <- sd(results)
cat("Precision of iterations (standard deviation): ", precision, "\n")
```

The code implements the Newton-Raphson method in R to find the root of the function.

DEVELOPMENT

The proposed methodology for incorporating the R Project into the teaching of numerical methods is organized into a series of steps that allow for the systematic planning, execution, and evaluation of the teaching intervention. The main stages of the process are described below:

1. Design of the teaching intervention: In the first stage, the teacher defines the specific learning objectives related to numerical methods and the use of R Project. The course topics to be addressed through R-supported activities are selected, such as solving nonlinear equations, numerical integration, or solving differential equations. Likewise, the evaluation criteria and expected outcomes (assignments, laboratory exercises, projects, reproducible reports, etc.) are established.
2. Selection of participants and context: Next, the group of students with whom the intervention will be implemented is defined (for example, a fourth-semester engineering course on numerical methods). The characteristics of the institutional context, the students' previous experience in programming, and their access to computer equipment are documented. This

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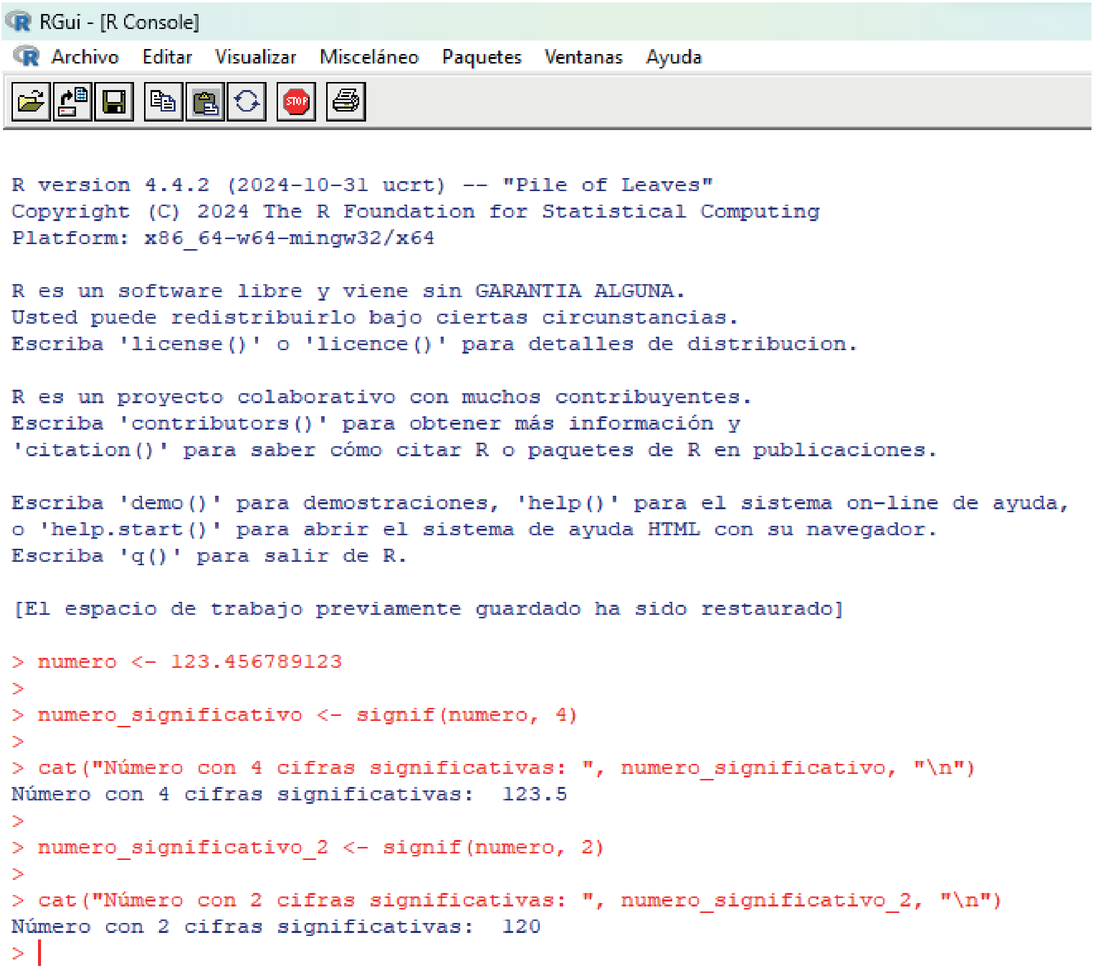
Code execution in R



RGui - [R Console]

Archivo Editar Visualizar Misceláneo Paquetes Ventanas Ayuda

```
R version 4.4.2 (2024-10-31 ucrt) -- "Pile of Leaves"
Copyright (C) 2024 The R Foundation for Statistical Computing
Platform: x86_64-w64-mingw32/x64

R es un software libre y viene sin GARANTIA ALGUNA.
Usted puede redistribuirlo bajo ciertas circunstancias.
Escriba 'license()' o 'licence()' para detalles de distribucion.

R es un proyecto colaborativo con muchos contribuyentes.
Escriba 'contributors()' para obtener más información y
'citation()' para saber cómo citar R o paquetes de R en publicaciones.

Escriba 'demo()' para demostraciones, 'help()' para el sistema on-line de ayuda,
o 'help.start()' para abrir el sistema de ayuda HTML con su navegador.
Escriba 'q()' para salir de R.

[El espacio de trabajo previamente guardado ha sido restaurado]

> numero <- 123.456789123
>
> numero_significativo <- signif(numero, 4)
>
> cat("Número con 4 cifras significativas: ", numero_significativo, "\n")
Número con 4 cifras significativas:  123.5
>
> numero_significativo_2 <- signif(numero, 2)
>
> cat("Número con 2 cifras significativas: ", numero_significativo_2, "\n")
Número con 2 cifras significativas:  120
> 
```

Figure 1. Execution of significant figures code in R.

Execution of the code in R

```
RGui - [R Console]
Archivo  Editar  Visualizar  Misceláneo  Paquetes  Ventanas  Ayuda

Escriba 'contributors()' para obtener más información y
'citation()' para saber cómo citar R o paquetes de R en publicaciones.

Escriba 'demo()' para demostraciones, 'help()' para el sistema on-line de ayuda,
o 'help.start()' para abrir el sistema de ayuda HTML con su navegador.
Escriba 'q()' para salir de R.

[El espacio de trabajo previamente guardado ha sido restaurado]

> f <- function(x) x^2 - 2
> df <- function(x) 2*x
>
> newton_raphson <- function(x0, tol = 1e-6, max_iter = 100) {
+   iter <- 0
+   x <- x0
+   while (abs(f(x)) > tol && iter < max_iter) {
+     x <- x - f(x) / df(x)
+     print(x)
+     iter <- iter + 1
+   }
+   return(x)
+ }
>
> resultados <- c(newton_raphson(1.5), newton_raphson(1.6), newton_raphson(2))
[1] 1.416667
[1] 1.414216
[1] 1.414214
[1] 1.425
[1] 1.414254
[1] 1.414214
[1] 1.5
[1] 1.416667
[1] 1.414216
[1] 1.414214
> cat("Resultados de las iteraciones del método de Newton-Raphson: ", resultados, "\n")
Resultados de las iteraciones del método de Newton-Raphson:  1.414214 1.414214 1.414214
>
> precision <- sd(resultados)
> cat("Precisión de las iteraciones (desviación estándar): ", precision, "\n")
Precisión de las iteraciones (desviación estándar):  3.392557e-10
> |
```

Figure 2. Execution of the Precision code in R.

information is key to adjusting the complexity of the activities and anticipating possible technical or conceptual difficulties.

3. Design of materials and instruments: In this step, the necessary teaching materials are developed: practice guides with step-by-step instructions, annotated R scripts, R templates, and evaluation rubrics. At the same time, data collection instruments are designed to evaluate the effectiveness of the intervention, such as perception questionnaires, diagnostic and final tests on numerical methods, and observation grids for classroom work.
4. Implementation of activities with R Project: Once the materials are prepared, the class and lab sessions are carried out. The teacher introduces the R environment and guides the students in carrying out the exercises, encouraging them to modify the parameters of the algorithms, interpret the numerical results, and discuss the differences between analytical and approximate solutions. Collaborative work is encouraged so that students share programming strategies and verify results.
5. Data collection and analysis: During and after implementation, data derived from the designed instruments are collected: test results, learning products (scripts, reports, projects), questionnaire responses, and teacher observations. Next, a quantitative and qualitative analysis of this information is performed to identify progress in understanding numerical methods , changes in attitudes toward programming and the use of free software, as well as recurring difficulties in using R.
6. Feedback and continuous improvement: Finally, based on the results of the analysis, conclusions are drawn about the effectiveness of the intervention and proposals for improvement are formulated for future editions of the course. This may include adjustments to the sequence of content, the complexity of the exercises, the support provided to students, or the integration of new R Project packages and resources. In this way, the methodology is conceived as a cycle of continuous improvement that seeks to optimize the teaching of numerical methods through the use of R.

DISCUSSION AND ANALYSIS OF RESULTS

At the Villahermosa campus of the National Technological Institute of Mexico, the Numerical Methods course in the Computer Systems Engineering program is fundamental for the development of technical skills that enable students to tackle complex problems in modeling and numerical simulation. Through this course, students are expected to acquire skills in the use of numerical algorithms applied to different areas of engineering and science. The main objective is for students not only to understand the theoretical methods, but also to be able to implement, analyze, and apply them to real-world scenarios using specialized software such as R Project.

In implementing this course, R Project was integrated as the main tool for numerical analysis due to its accessibility, code integration capabilities, and open approach that encourages reproducibility. Throughout the semester, students completed exercises and projects involving the programming of numerical methods and the interpretation of results using this software. The activities were designed to offer students a practical approach, in which, through simulations, applications, and real projects, theory and practice could be integrated in a coherent manner.

The results obtained in the course indicate that the use of R Project not only improved students' conceptual understanding of numerical methods, but also enhanced their skills in programming, data analysis, and visualization of results. The interactive environment and the ability to easily modify algorithm parameters allowed students to experiment with numerical solutions in a more dynamic and visual way, facilitating the understanding of complex concepts such as truncation error, convergence of iterative methods, and solving systems of equations. In addition, the integration of R to document and present results allowed students to improve their scientific and written communication skills.

When comparing the traditional methodology, based mainly on manual calculations and theoretical solutions, with the approach implemented using R Project, a significant change can be observed in the way students interact with numerical methods. While in traditional approaches students tend to focus on formulas and manual calculations, the use of R allows for greater exploration, facilitating understanding of the usefulness of numerical methods in solving real-world problems. This change in approach makes students feel more motivated and empowered as they see the results of their work immediately, as well as being able to interact with the data and see the impact of the decisions made at each step of the process. The software also allows them to verify the precision and accuracy of their solutions, which encourages critical reflection on the validity of the results obtained.

However, certain challenges must be acknowledged. Learning R Project can be challenging for students who have no previous programming experience, especially in the early stages of the course. Some students found it difficult to work with R syntax and to understand the structure of the scripts and the logic behind the code. To address these challenges, it is recommended that a more detailed introduction to the R language be offered before starting to use numerical methods, which could include a small basic programming unit, focusing on the most essential functions so that students gain confidence in their use.

Despite the initial challenges, the use of the R Project opened up new learning opportunities for students. One of the most notable benefits was the ability to work with real data, which made students perceive the learning of numerical methods as a useful tool applicable to real-world problems. In addition, the use of R encourages the development of cross-cutting skills such as programming, critical analysis, and problem solving, which are essential for the professional profile of a computer systems engineer. In the future, it is suggested that the integration of R Project with other software tools, such as databases and simulation systems, be strengthened to expand the applications of the course and allow students to experiment with more complex and multidisciplinary problems.

In short, the implementation of the R Project in the Numerical Methods course at the Villahermosa campus of the National Technological Institute of Mexico has been a success in terms of improving student learning. The integration of this tool has allowed for a deeper understanding of numerical methods, encouraged the development of additional skills such as programming and data visualization, and brought students closer to professional practice through the use of free and accessible software. With some adjustments to the teaching of R and student support, this approach could become a replicable model in other higher education institutions.

REFERENCES

Bloomfield, V. A. (2014). Using R for numerical analysis in science and engineering. CRC Press.

Briz-Redón, Á., & Serrano-Aroca, Á. (2018). Learning mathematics through the R programming language in secondary education. Educación Matemática, 30(1), 133–162. https://doi.org/10.24844/EM3001.05

Chapra, S. C. (2018). Applied numerical methods with MATLAB for engineers and scientists (4.ª ed.). McGraw-Hill Education.

Chapra, S. C., & Canale, R. P. (2015). Numerical methods for engineers (7th ed.). McGraw-Hill Education.

Cheang, W. K. (2004). The use of R language in mathematics teaching and computation. In Proceedings of the 9th Asian Technology Conference in Mathematics (ATCM 2004) (pp. 402–409). National Institute of Education. https://atcm.mathandtech.org/EP/2004/2004C142/fullpaper.pdf

Parra, M. I., Sanjuán, E. L., Robustillo, M. C., & Pizarro, M. M. (2023). Using R for teaching and research. arXiv. https://doi.org/10.48550/arXiv.2306.12200

R Core Team. (2025). R: A language and environment for statistical computing. R Foundation for Statistical Computing. https://www.r-project.org/

Triana, J., & Ferro, L. (2021). Finite difference methods in image processing. Selecciones Matemáticas, 8(2), 411–416. https://doi.org/10.17268/sel.mat.2021.02.17

Fernández Mena, A. L., Rodríguez Fernández, L., Rodríguez Fernández, M. A., Rodríguez Magaña, M. A., & Tamayo Uribe, R. E. (2023). Implementación de R Project aplicado a la enseñanza de la estadística en la educación superior. *REVISTA IPSUMTEC*, *6*(5), 177–184. https://doi.org/10.61117/ipsumtec.v6i5.237

Fernández Mena, A. L., Pérez Reyes, A., Rodríguez Fernández, L., Torres Magaña, M. P., & Rodríguez Fernández, M. A. (2023). R Project aplicado a la enseñanza de las ciencias exactas. *REVISTA IPSUMTEC*, *6*(5), 130–138. https://doi.org/10.61117/ipsumtec.v6i5.232

Mora Flores, W. (2016). Cómo utilizar R en métodos numéricos. *Revista Digital: Matemática, Educación E Internet*, *16*(1). https://doi.org/10.18845/rdmei.v16i1.2480

Prokop, Tricia & Wininger, Michael. (2018). A Primer on R for Numerical Analysis in Educational Research. Frontiers in Education. https://doi.org/10.3389/feduc.2018.00080