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Didactics of mathematics, free software and resource development through Learnr and Shiny.

Didáctica de las matemáticas, software libre y desarrollo de recursos mediante Learnr y Shiny.

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Abstract

Interactive web pages for teaching statistics were developed, using the Shiny and Learnr tools (R programming language) and released for open access. The contents were selected from the official curricula and from the bibliographic review of previous innovations made by other authors. An action-research was carried out in the virtual classroom and a questionnaire was made by means of a survey, with the participation of 27 male and 59 female students of the subject "Mathematics and its didactics I", 2nd year of the Degree in Primary Education (teacher training). The usefulness of these web resources was tested by using them for the practical virtual teaching of the subject during the confinement caused by COVID-19. The evaluations collected in the survey showed that the virtual activities developed improved the students' attitudes and competences.

Keywords: Didactics, Statistics, R project, Free Software.

Resumen

Se desarrollaron páginas web interactivas para la enseñanza de la estadística, empleando las herramientas Shiny y Learnr (lenguaje de programación R) y publicándolas para su ejecución libre por parte de cualquier persona interesada. Se seleccionaron contenidos a partir de los currículos oficiales y de la revisión bibliográfica de innovaciones previas de otros autores. Se llevó a cabo una investigación-acción en el aula virtual y un cuestionario mediante una encuesta, con la participación de 27 alumnos y 59 alumnas de la asignatura de “Matemáticas y su didáctica I” de 2º curso del Grado en Educación Primaria (formación para ejercer como Maestros). Se comprobó la

utilidad de estos recursos webs empleándolos para la docencia práctica virtual de la asignatura durante el confinamiento provocado por el COVID-19. Las valoraciones recogidas en la encuesta mostraban que las actividades virtuales desarrolladas mejoraron las actitudes y las competencias del alumnado.

Palabras clave: Didáctica, Estadística, Lenguaje R, Software libre.

Introduction

State of the problem

Pre-higher education in Spain is structured in four stages: Child Education (children from 0 to 6 years old), Primary Education (from 6 to 12 years old), Obligatory Secondary Education (from 12 to 16 years old), and High School (from 18 to 20 years old). When analyzing the normative, it is observed that specific "blocks" of "Statistics and Probability" within the subject of Mathematics, for Primary Education (Real Decreto 126/2014, 2014) as well as for Secondary Education and High School (Real Decreto 1105/2014, 2014) are included.

R is a language and a programming environment that allows data managing and treatment (R Core Team, 2020). It was initially developed by Robert Gentleman and Ross Ihaka from the Statistics Department of Auckland University in 1993. R is an object-oriented language, destined for statistical data analysis and representation. It is about free-use software, it has great implementation at universities (Maurandi *et al.*, 2013), furthermore, in the entrepreneur world. It is a free tool (licencia GNU), multiplatform and, compatible with different formats and, it can be downloaded at https://www.r-project.org/ (R Core Team, 2020) corresponding to a project with an 'international scope, based on a users' community that collaborated on the creation and shared usage of internet resources. All the already mentioned characteristics allow R language multiple applications related to education and, particularly, in the teaching of the mathematics contents. For instance, in Barriuso *et al.* (2013) and Alba (2017) work proposals to the teaching of Statistics using language R to the teaching at pre-university and university studies can be found. The project exposed in this article it is also focused on the teaching of Statistics, it is also important to state, that the R language has also been applied to the teaching of other pre-university mathematics contents (Briz & Serrano, 2018), considering that it is a powerful programming language.

In recent years, the area of Didactic Mathematics of the University of Murcia has started a research line (Maurandi & Castejón, 2019) whose study objects are:

- Didactic of Mathematics
- Development and informatic resources implementation,
- Innovation in Teacher training (for primary, secondary, and high school teachers).

Election of available and free of charge Internet resources use pursuits the opportunity to establish an open pedagogy for students to experiment with such contents, at any place and at any time, as well as with different groups. Murcia Region's curriculum official pre-university education curriculum has been taken into account. Normative for this Autonomous Community (Decreto 220/2015, 2015) establishes specifically the use of new technologies in teaching mathematics to solve problems, proof solutions, make simulations with distinct departure conditions, and helping to a better concept understanding. Besides, during the school cycle 2019/2020, it was necessary to count on technological tools for virtual teaching when the sanitary crisis caused by COVID-19 limited the possibilities for a face-to-face teaching context (Real Decreto 463/2020, 2020).

Background

The R language has evolved with the collaborative philosophy previously described. Over the years it has incorporated new tools and interphases that have been used with teaching applications. Pérez *et al.* (2019) introduced in a teaching environment interactive application based on Shiny which is a library that facilitates the creation of interactive web applications directly from R. Through this tool students are allowed to modify data or execute examples from a visual web interphase, where nor command introduction nor code modification is necessary. Likewise, Capitán *et al.* (2019) take advantage of the "R Commander" offered opportunities that are a users' graphic interphase.

In 2017, the Learnr (*"Interactive Tutorials for R"*) pack was incorporated into the R Language (R Core Team, 2020). This library can be freely downloaded along with the corresponding manual, and it allows the generation of an interactive web page that combines the text, the figures, the videos, the exercises, and the questionnaires to create tutorials that promote self-learning. The generated webpages provide the advantage that the implemented exercises can be directly executed from the user's Internet Explorer program, it is not necessary for the student to download R or to install it on his/her desktop.

Objectives

In Spain, Primary Education teachers are formed by studying the "Grado en Educación Primaria" Bachelor's Degree, which takes four year-courses. The subject "Mathematics and its Didactic" from the 2nd year course of the Bachelors' Degree in Primary Education at Murcia's University is planned to be imparted face-to-face methodologies. The virus COVID – 19 provoked an international sanitary crisis, and from the second half of the year-course 2019/2020, the whole Spanish population had to be in confinement. In this context, the authors proposed implementing courses to allow the virtual teaching of the practicum part of the Statistics and Probability contents. With the following objectives:

1. To identify the contents of Statistics and Probability present in the Primary, Secondary, and High School Education official curriculum.

2. To carry out a bibliographic review of previous papers related to the application of the R language within the teaching of Statistics and Probability contents,

3. to prepare didactic activities and their implementation in the own interactive webpages developed through the Shiny and Learnr packages. The contents of these resources were selected and elaborated from the previous stages (1 and 2).

4. To provide public access to any person interested in freely execute the resources developed within this project. To employ such access and implemented resources in teacher training of mathematics in the virtual teaching modality.

The official program of the subject "Mathematics and its didactic I" from the Degree on Primary Education is found in the degree obtention Teachers' Guides (Facultad de Educación de la Universidad de Murcia, 2020). The developed resources were implemented in the teaching practice for the "Theme 6. Organization and Representation of the information. Materials and Didactic Resources. Difficulties and errors". The contents for this theme are:

6.1.- Statistics and its applications.

6.2.- Statistics variables. Tables and graphics.

6.3.- Measures of central tendency and dispersion of a frequency distribution.

6.4.- Normal Distribution Applications.

6.5.- Statistic applications to daily life.

6.6.- Teaching Statistics Materials and resources.

Materials and Methodology

Participants

The interactive webpages implemented in this project were published on internet, so such teaching resources were accessible to any participants interested in their free execution. The didactic usefulness of the tools was checked through its implementation in the virtual teaching practice to the Teaching Faculty of Murcia University students. 27 male, and 59 female students, who were studying the "Mathematics and its Didactics I" subject from the 2dn course of the Primary Education bachelor's degree at Murcia University, and who selected for convenience.

The taught content corresponded to the theme of Statistics and Probability. It was the theme of the subject last programmed by the dates that coincided with the sanitary confinement that took place during part of the school year 2019/2020. This fact disturbed the normal development of the subject, which originally was planned based on a face-to-face to methodology, nevertheless it had to be imparted virtually for this period. Previous students' mathematics training was heterogenous, even though, 97% of the class had already coursed high school. Nevertheless, it was found that only 74% of class had taken mathematics within the two school-years that this educational stage takes place in Spain.

Technics and instruments

A descriptive, no experimental qualitative and quantitative approach was carried out throughout quantitative technics and instruments. More specifically, action-research research designed was implemented, where gathered data for analysis and discussion was obtained through a Likert scale questionnaire.

It has already been specified that this project is a teaching intervention with students of Primary Education Degree at Murcia University thus future teachers within the educational Spaniard system. Once participants did the training activities, completed the surveys, and emitted

ratings on the raised questions. Ratings corresponded to a scale from 1: "I totally disagree" to 7: "I totally agree". The raised questions were aimed to analyzed if the training activities developed had improved participants' attitudes and mathematics competence facing their future as teachers.

Procedure

References to the normative for Spain and the Region of Murcia's education system were exposed in the introduction, as the literature reviewed, which allowed the authors to select and elaborate the contents for implementation of the web resources of this project. Previous contributions from different authors, who had been interested in teaching innovation through using Language R in the teaching of mathematics, were analyzed. To it do so, Internet searches were carried out, by using the Google Academic and Dialnet tools, introducing the following keywords: software, R, statistics, probability, primary education, compulsory secondary education, high school. Those indicated searches results were, in the case of the ones that adjusted to the project's objectives, were taken into consideration, giving priority to freely accessible documents.

The introduction describes two tools, Shyni and Learn, which belong to the R language, and which allowed the authors to implement their resources based on this free software. First, the exercises proposed by Barriuso *et al.* (2013) were implemented in this project, as they were considered of great interest. They were updated regarding their format to adapt their contents to a web environment. Subsequently, other exercises, also developed by the authors of this work, who took the regulations and other bibliographic references presented in the introduction as their orientation, were included in the interactive pages.

The resources developed were published on two interactive web pages with free access to anyone interested in running them. Virtual practical teaching was given through the joint use of the institutional virtual classroom tools (https://www.um.es/aulavirtual/) and the interactive pages developed by the authors in this project. The virtual classroom of the University of Murcia provides videoconference, space to share digital resources, forums, private messages, delivery of assignments and surveys. The interactive pages implemented allowed the students to execute the practical activities through the browser without having to download R on their computers.

In the previous sections, it has been explained that the resources developed within this project were used in effective practical teaching with future teachers who were studying at the Faculty of Education in Murcia. The health crisis caused by COVID forced the virtual teaching in part of the content planned for the 2019/2020 academic year, although a face-to-face modality had been initially planned as is the usual norm in this institution. This assessment survey was prepared, configured and published using the institutional survey tool of the University of Murcia (ATICA, 2020), structured in the following blocks: I. Socio-demographic block, II. Block on attitudes, II. Block on competences, IV. Final block.

Information analysis

As the first source of information, the experience of the intervention in the virtual classroom was available. It was found that the teaching activity could be normally developed in the virtual environment created by using free software. The second source of information was the data gathered through the survey (via the web) that corresponded to evaluations adjusted to a Likert scale. This made possible the gathering of students' evaluations on their attitude's improvement and their development regarding mathematics. The gathered evaluations were analyzed with the free software statistical package R calculating the means and standard deviations corresponding to each raised question.

Results and discussion

The authors implemented their proposals using the Shiny and Lerarnr libraries so that students could interactively work on a series of practical activities through the browser, from any location and at any time, without the need to install the R language locally. This section includes (Figures 1 to 9) screenshots of the interactive web pages that were implemented and published in the following locations available to the public to anyone interested in running the applications they contain: https://amaurandi2.shinyapps.io/educaR2/ , https://joserios.shinyapps.io/APPTFM/ .

The exercises that Barriuso *et al.* (2013) included in their work were initially implemented given their interest stated in the first references analyzed when conducting the literature review for this project. The activities included in this article corresponded to "Grouping in intervals" and "Dice throwing" executed in a local environment through the use of commands; For the present work, an update of formats was carried out using an implementation of the same activities in an

interactive web environment that the student executed directly through the browser. After consulting the subsequent references (presented in the Introduction), additional activities were implemented. Finally, the developed resources allow the following activities to be carried out:

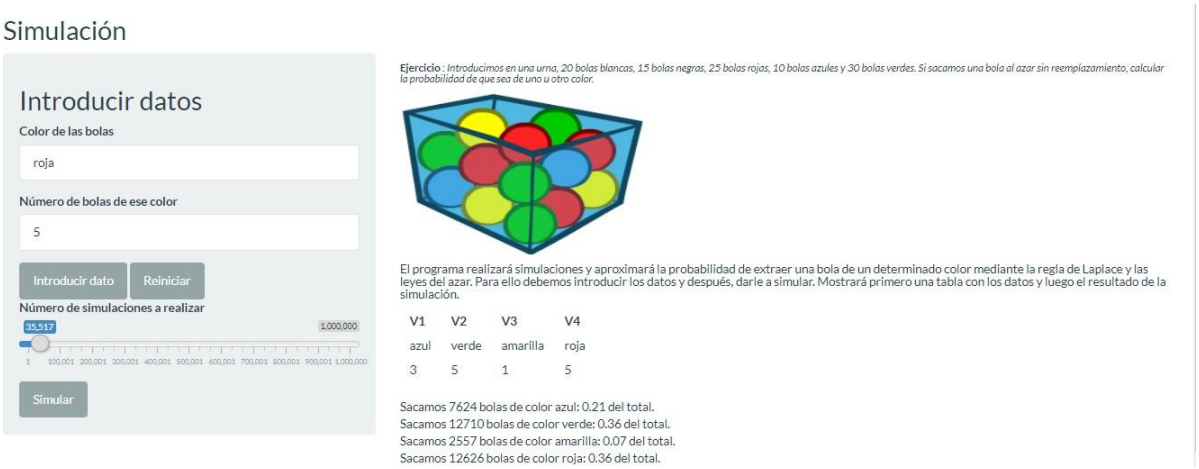
- **Exercises.** Histogram and Bar Chart, Sector Chart, Position and Scatter Parameters, Random Event Simulation, and Probability Calculations.

- **Practices**. 1. Qualitative Variable. 2. Quantitative Variable. 3. Throwing Dice. 4. Group in Intervals. 5. Mean versus Median.

Figure 1 shows one of the exercises implemented, it involves the simulation of a random event, the extraction of balls from an urn, and the calculation of associated probabilities. In this application, the Shiny library is used, but the use of the Learnr library is not yet introduced. The screenshot allows observing the executable visual interface through the explorer that allows the user to carry out the simulation as many times as he wishes, modifying the starting conditions.

Figure 1.

Exercise simulating a random event and calculating probabilities.

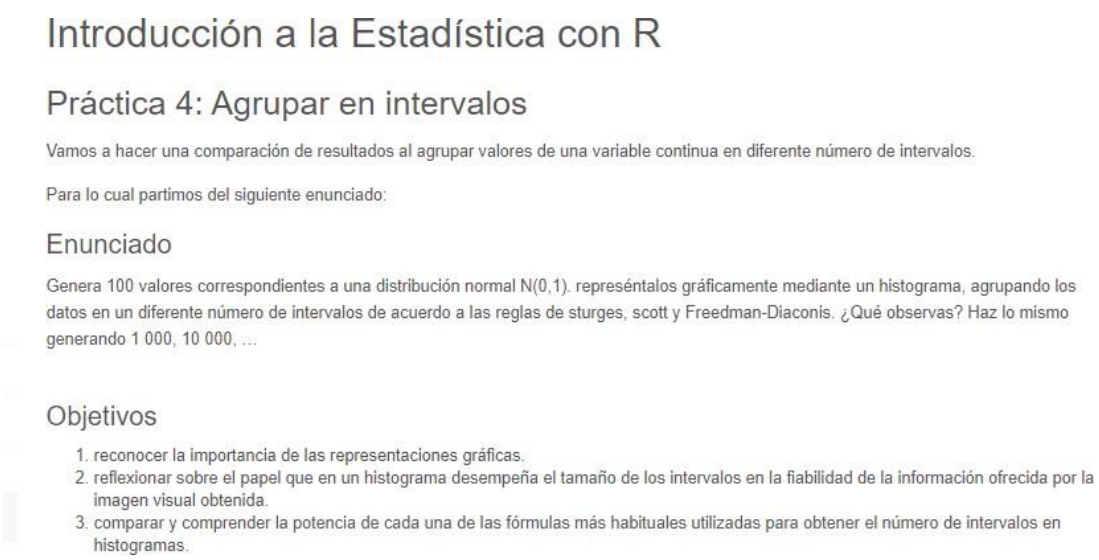


Source: author's own elaboration.

The screenshot corresponding to the statement of the practice "Grouping in intervals" in Figure 2 is shown.

Figure 2.

Statement and objectives of the activity "Practice 4. Grouping in intervals".

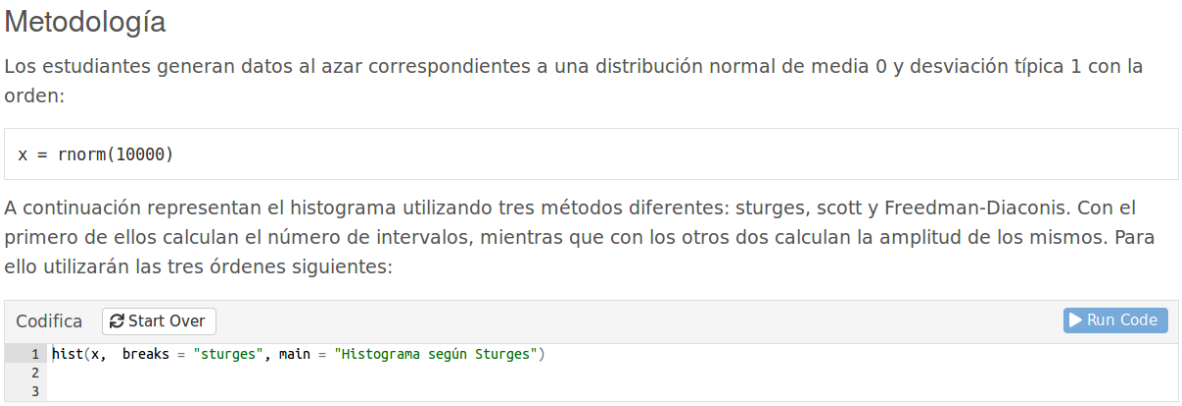


Source: author's own elaboration.

Continuing with the "Grouping in intervals" activity, figures 3 and 4 show screenshots of the resolution methodology shown to the students as the result of one of the configurations (histogram according to Sturges). In this case, the use of the Learnr library for the implementation of the resource is already introduced, you can appreciate the ease of being able to enter and execute R code from the browser itself with the "Run Code" button without having to install the R language in the local team. Finally, Figure 5 shows the screenshot corresponding to the resolution methodology in which the students are proposed to investigate other configurations.

Figure 3.

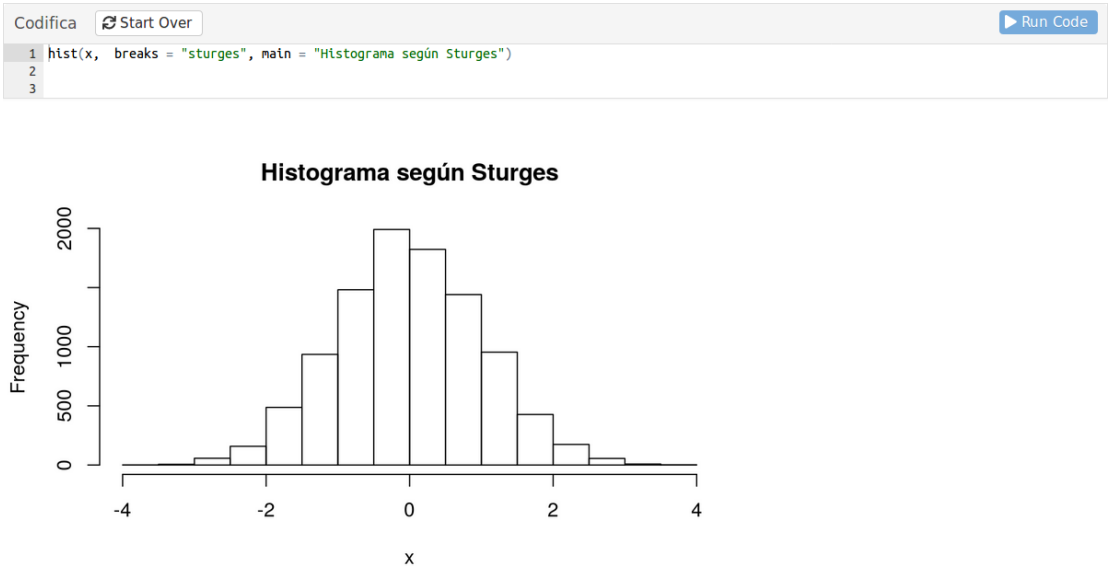
Methodology of the activity "Practice 4. Grouping in intervals".



Source: author's own elaboration.

Figure 4.

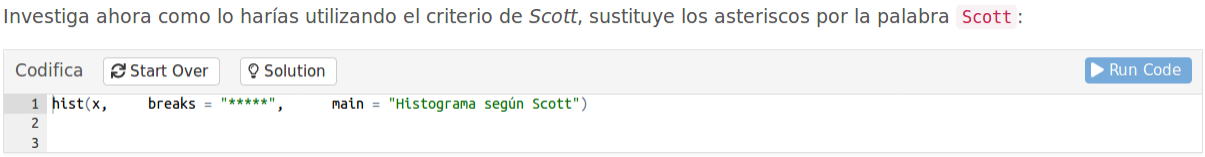
Results of the activity "Practice 4. Grouping in intervals".



Source: author's own elaboration.

Figure 5.

Other settings from "Practice 4. Group in intervals".

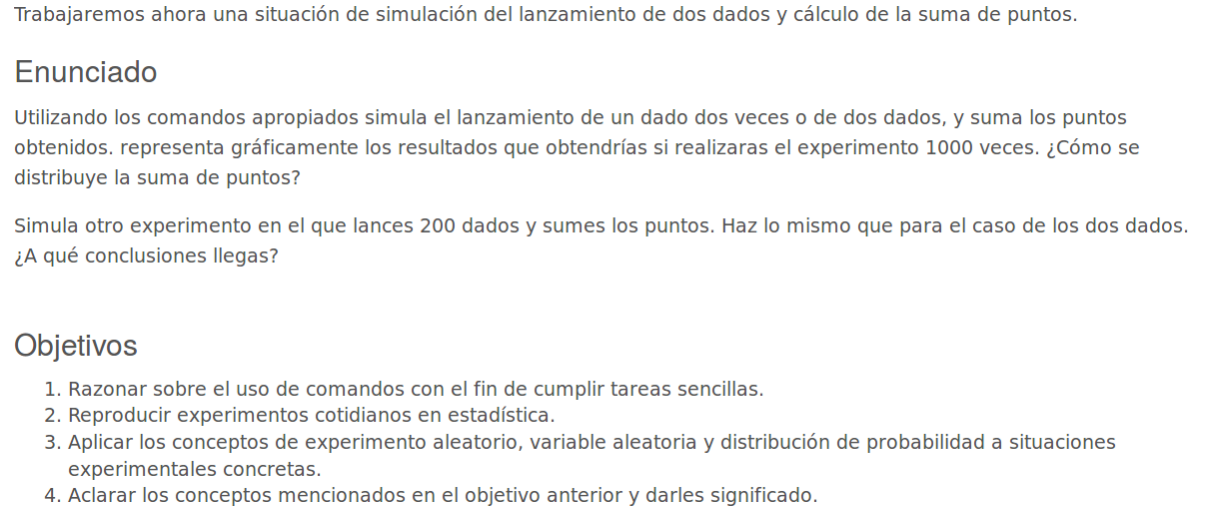


Source: author's own elaboration.

Figure 6 shows the activity "Throwing the dice", during which we work on simulations of the random experiment of throwing two dice and obtaining the corresponding score. You can see the screenshot corresponding to the Statement and Objectives.

Figure 6.

Statement and objectives of the activity "Throwing the dice".



Source: author's own elaboration.

Continuing with the activity "Throwing the dice", figures 7 and 8 are shown below, where the two screenshots corresponding to the launch of the simulations as well as the obtaining and representation of the results in the browser can be seen.

Figure 7.

Simulations of the activity "Throwing the dice".

Para sumar los puntos podemos utilizar:

```
sum(sample(1:6,2,rep=TRUE))
```

```
## [1] 5
```

Source: author's own elaboration.

Figure 8.

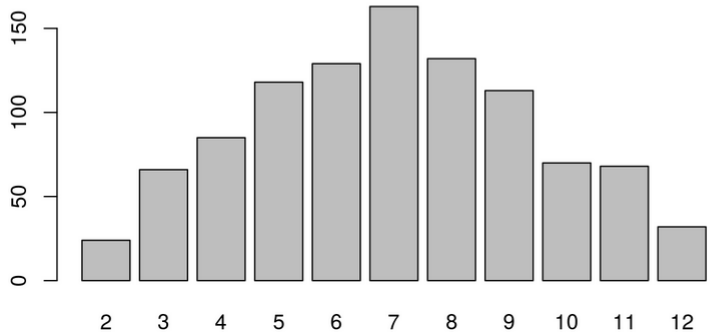
Simulations and representation of results of the activity "Throwing the dice".

Si lo que pretendemos es simular el mismo experimento 1000 veces utilizamos la siguiente instrucción:

```
t = sapply(1:1000, function(x) {
    sum(sample(1:6, 2, rep = TRUE))
})
```

Para representar gráficamente los datos procedemos con la instrucción:

```
barplot(table(t))
```

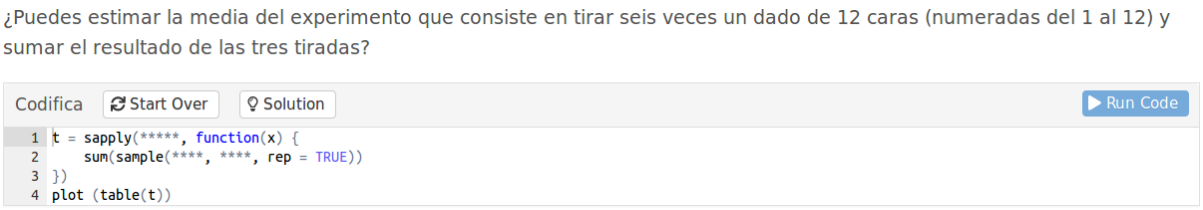


Source: author's own elaboration.

Continuing with the activity "Throwing the dice" Figure 9 shows where an exercise was proposed to the student.

Figure 9.

Proposed exercise of the activity "Throwing the dice".

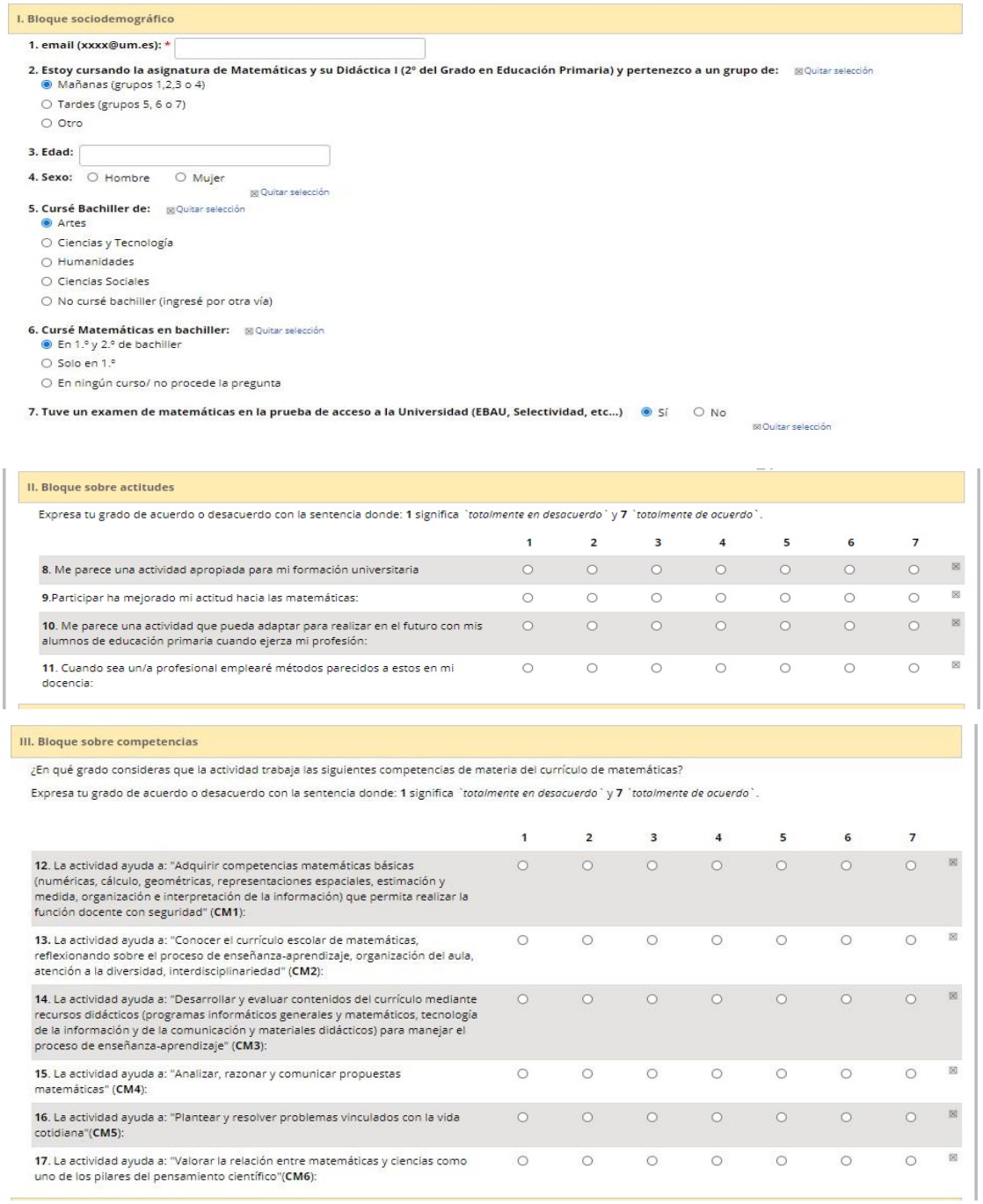


Source: author's own elaboration.

Part of the activities collected in our web resources were exposed in the videoconferences scheduled with the entire group, the remaining activities were developed independently by the students. Subsequently, the delivery of the work carried out and the survey (anonymous and voluntary) to assess the training received was required. The authors prepared the survey using the corresponding institutional tool (ATICA, 2020) and published it at the addresshttps://encuestas.um.es/encuestas/estadistica1.cc (Figure 10). The survey was structured in four blocks (Figure 10). In Block I, information on the participating students corresponding to both general data and their previous mathematical training was gathered. In Blocks II, and III students turned in evaluations regarding the given statements on a scale from 1: "totally disagree" to 7: "totally agree". In Block II, evaluations corresponded to the students' attitudes towards the activities, towards mathematics in general, and regarding their future teaching practice. In Block III, evaluations corresponded to the usefulness that the students perceived in the activities to achieve the development of competences provided for in the degree. Block IV allowed students to freely add comments.

Figure 10.

Block of the valoration survey.



I. Bloque sociodemográfico

1. email (xxxx@um.es): *

2. Estoy cursando la asignatura de Matemáticas y su Didáctica I (2º del Grado en Educación Primaria) y pertenezco a un grupo de: Quitar selección
- Mañanas (grupos 1,2,3 o 4)
- Tardes (grupos 5, 6 o 7)
- Otro

3. Edad:

4. Sexo: Hombre Mujer
Quitar selección

5. Cursé Bachiller de: Quitar selección
- Artes
- Ciencias y Tecnología
- Humanidades
- Ciencias Sociales
- No cursé bachiller (ingresé por otra vía)

6. Cursé Matemáticas en bachiller: Quitar selección
- En 1.º y 2.º de bachiller
- Solo en 1.º
- En ningún curso/ no procede la pregunta

7. Tuve un examen de matemáticas en la prueba de acceso a la Universidad (EBAU, Selectividad, etc...) Sí No
Quitar selección

II. Bloque sobre actitudes

Expresa tu grado de acuerdo o desacuerdo con la sentencia donde: **1** significa `*totalmente en desacuerdo*` y **7** `*totalmente de acuerdo*`.

	1	2	3	4	5	6	7
8. Me parece una actividad apropiada para mi formación universitaria	○	○	○	○	○	○	○
9.Participar ha mejorado mi actitud hacia las matemáticas:	○	○	○	○	○	○	○
10. Me parece una actividad que pueda adaptar para realizar en el futuro con mis alumnos de educación primaria cuando ejerza mi profesión:	○	○	○	○	○	○	○
11. Cuando sea un/a profesional emplearé métodos parecidos a estos en mi docencia:	○	○	○	○	○	○	○

III. Bloque sobre competencias

¿En qué grado consideras que la actividad trabaja las siguientes competencias de materia del currículo de matemáticas?

Expresa tu grado de acuerdo o desacuerdo con la sentencia donde: **1** significa `*totalmente en desacuerdo*` y **7** `*totalmente de acuerdo*`.

	1	2	3	4	5	6	7
12. La actividad ayuda a: "Adquirir competencias matemáticas básicas (numéricas, cálculo, geométricas, representaciones espaciales, estimación y medida, organización e interpretación de la información) que permita realizar la función docente con seguridad" (**CM1**):	○	○	○	○	○	○	○
13. La actividad ayuda a: "Conocer el currículo escolar de matemáticas, reflexionando sobre el proceso de enseñanza-aprendizaje, organización del aula, atención a la diversidad, interdisciplinariedad" (**CM2**):	○	○	○	○	○	○	○
14. La actividad ayuda a: "Desarrollar y evaluar contenidos del currículo mediante recursos didácticos (programas informáticos generales y matemáticos, tecnología de la información y de la comunicación y materiales didácticos) para manejar el proceso de enseñanza-aprendizaje" (**CM3**):	○	○	○	○	○	○	○
15. La actividad ayuda a: "Analizar, razonar y comunicar propuestas matemáticas" (**CM4**):	○	○	○	○	○	○	○
16. La actividad ayuda a: "Plantear y resolver problemas vinculados con la vida cotidiana"(**CM5**):	○	○	○	○	○	○	○
17. La actividad ayuda a: "Valorar la relación entre matemáticas y ciencias como uno de los pilares del pensamiento científico"(**CM6**):	○	○	○	○	○	○	○

Source: author's own elaboration.

When students completed the surveys, they issued their assessment regarding the raised questions, which corresponded to opinions on a scale from 1: "totally disagree" to 7: "totally agree". Table 1 shows the mean and standard deviation of the collected data. Globally, it was found that students showed a general agreement that the activities carried out had improved their attitudes and competencies regarding mathematics and that they had also allowed them to experiment with a type of activities and a methodology that they consider is appropriate to use once they found themselves teaching.

Table 1.

Raised questions survey and evaluations obtained.

Express your degree of agreement or disagreement with the sentence where: 1 means "totally disagree" and 7 means "totally agree".	**Average Valuarions**	**Standard Deviation Valuations**
It seems as an appropriate activity for my bachelors' degree training.	5,1	1,5
Participating has improved my attitude towards math.	4,6	1,7
It seems like an activity that I can adapt to carry out in the future with my primary school students when I practice my profession.	4,7	1,8
When I am a professional, I will use methods similar to these in my teaching.	4,9	1,8
The activity helps to: "Acquire basic mathematical skills (numerical, calculus, geometric, spatial representations, estimation, and measurement, organization and interpretation of information) that allow the teaching function to be carried out safely" (CM1).	4,9	1,4
The activity helps to: "Know the school mathematics curriculum, reflecting on the teaching-learning process, classroom organization, attention to diversity, interdisciplinarity" (CM2).	4,2	1,7
The activity helps to: "Develop and evaluate contents of the curriculum through didactic resources (general and mathematical computer programs, information and communication technology and didactic materials) to manage the teaching-learning process" (CM3).	5,3	1,6
The activity helps to: "Analyze, reason and communicate mathematical proposals" (CM4).	5,1	1,5
The activity helps to: "Raise and solve problems related to everyday life" (CM5).	4,6	1,7
The activity helps to: "Value the relationship between mathematics and science as one of the pillars of scientific thought" (CM6).	5,0	1,6

Source: author's own elaboration.

Conclusions

Within the introduction of this project, references showed interest in the use of R Language in the teaching of Statistics and Probability. From that context, four objectives, specified in the introduction section, were developed during this action-research work. In this process, three teaching innovations resulted to be the main contributions of this project:

1. Implementation of an interactive web page using and taking advantage of the (free) Learnr package features.
2. Adaptation of the resources implemented in the teaching needs of the Didactics of Mathematics of the Grade of Primary Education
3. The use of implemented resources in practical virtual teaching virtual mode, with the students of this Degree (future to be teachers in the pre-university stages) as the evaluation by the recipients of the training given.

Through the assessment done by the participants, it was observed that there was an agreement that activities developed in the project improved their attitudes regarding mathematics. Mainly, because participants considered that the activities were suitable for their university studies. Then, because these students, who will practice as Teachers once they finish their studies, showed in their assessment that in the future, they will propose and, or use similar methods to those experimented when receiving this intervention's training.

The other set of appreciations that participants emitted indicated that the activities help them develop their mathematics competence (CM) that are propper for their degree obtention.

> • "Acquire basic mathematical skills (numerical, calculus, geometric, spatial representations, estimation, and measurement, organization and interpretation of information) that allow the teaching function to be carried out safely" (CM1).
> • "Know the school mathematics curriculum, reflecting on the teaching-learning process, classroom organization, attention to diversity, and interdisciplinarity" (CM2).
> "Developing and evaluating curriculum content through didactic resources (general and mathematical computer programs, information and communication technology and didactic materials) to manage the teaching-learning process" (CM3).

- "Analyze, reason, and communicate mathematical proposals" (CM4).
- "Raise and solve problems related to everyday life" (CM5).
- "Value the relationship between mathematics and science as one of the pillars of scientific thought" (CM6).

The best evaluation rates were obtained (Table 1) for the development of the CM3 competence, which is the one that explicitly refers to the management of computer programs in school teaching-learning processes. It was also observed that in the case of the CM2 competence the lowest evaluations were obtained (Table 1) and that there is room to try to improve (with future interventions) the evaluations of all the attitudes and competences that have been studied.

In future interventions, it is expected to employ improved web resources development, for this study, the application of the first version, that is the ones that has been implemeted at this moment, has been exposed.

For future interventions, it is expected to employ improved web resources development. For this study, the application of the first version is the one that was implemented at this moment. For this research study, a virtual methodology was applied without having previously been planned due to the unexpected situation that caused the sanitary confinement (Royal Decree 463/2020, 2020). For future studies, it is advisable to overcome this limitation by carrying out teaching planning with some advance. In addition, it would be interesting to carry out new studies to expand the amount of available data to gather assessments from different groups of students, and, or with different groups of teachers, and or to propose more in-depth analyzes using more sophisticated statistical tools.

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