Innovation in statistical learning: friendly Bayesian inference in the R programming language

Innovación en al aprendizaje estadístico: inferencia Bayesiana amigable en el lenguaje de programación R

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Abstract- This paper reports the successful implementation of the *runRabbit* program as an innovative tool for teaching Bayesian inference applied to quantitative genetics. The program, which is an interactive and didactic software designed using the R language, was used by students at the Master of Animal Breeding and Genetics and Reproduction Biotechnology of the Polytechnic University of Valencia to solve a frequent statistical problem. The results showed that *runRabbit* helped the students to understand the subject matter better, and they expressed high satisfaction with the program and a desire to use Bayesian inference to solve new challenges. Despite the small sample size of this preliminary study, it suggests that *runRabbit* is an effective and valuable learning tool for enhancing theoretical understanding of Bayesian inference. To corroborate these results, *runRabbit* will be tested in larger groups in future studies. Its potential extends beyond just quantitative genetics and could be applied to any subject utilizing Bayesian statistics.

Keywords: Bayesian Inference, runRabbit, quantitative genetics, graphics, R, TIC, active learning.

Resumen- Este trabajo describe la implementación del programa *runRabbit* como herramienta de aprendizaje innovadora para enseñar inferencia Bayesiana aplicada a la genética cuantitativa. El programa, un software didáctico e interactivo diseñado con el lenguaje R, fue utilizado por estudiantes del Máster en Mejora Genética Animal de la Universidad Politécnica de Valencia para resolver un problema estadístico habitual. *RunRabbit* ayudó a los estudiantes a comprender mejor la materia, que expresaron una gran satisfacción con el programa y el deseo de utilizar la inferencia Bayesiana para resolver nuevos desafíos. A pesar del pequeño tamaño muestral de este estudio preliminar, los resultados sugieren que *runRabbit* es una herramienta de aprendizaje efectiva para mejorar la comprensión teórica de la inferencia Bayesiana. Para corroborar estos resultados, *runRabbit* será probado en grupos más grandes en futuros estudios. Su potencial se extiende más allá de la genética cuantitativa y podría aplicarse a cualquier ámbito que utilice estadística bayesiana.

Palabras clave: Inferencia Bayesiana, runRabbit, genética cuantitativa, herramientas TIC, visualización, R, aprendizaje activo.

1. INTRODUCTION

The subject of Quantitative Genetics III at Animal Breeding and Genetics Master of the Universitat Politècnica de València (UPV) introduces students to the use of Bayesian statistics to solve genetic analyses. Bayesian school has a great potential for application in fields that require data analysis, such as animal breeding. The aim of this subject is to train professionals specialized in animal breeding, providing them with the necessary skills to apply Bayesian statistics in the field, as described in Blasco (2017). To understand Bayesian statistics, basic knowledge of classical statistics, algebra, and probability theory combined with Bayes' Theorem is required. However, many students are not familiar with these concepts or are exposed to Bayesian statistical analysis for the first time in this subject, which can make it complex for them.

So far, the methodology used in this subject has mainly focused on theoretical lectures. These are essential for a proper learning process, but without complementary practical sessions, theoretical lectures alone can lead the student to passivity, making it difficult to immediately assimilate the content and limiting critical and creative thinking (Atkins and Brown, 2002; Nichols, 2002). Therefore, it is important to complement lectures with practical sessions that help to clarify and consolidate the knowledge acquired (Coll Serrano et al., 2009), in which students can solve real exercises and problems. However, the lack of user-friendly and highly intuitive Bayesian inference software was a limiting factor in conducting practical sessions for Quantitative Genetics III subject. Although not many, there are some publicly available programs suitable for fitting Bayesian inference, but their use is not intuitive for beginners, the outputs are unclear, or they are programmed in outdated languages that offer little flexibility.

2. CONTEXT & DESCRIPTION

A. Need for implementation

In the field of animal breeding, it is common to solve statistical problems using software using classical frequentist and Bayesian theory. Although classical frequentist theory is widely used, it has the disadvantage of posing serious interpretation problems that often lead to misinterpretation of results. This is the case when testing the significance of hypothesis tests using *p-values* (Amrhein et al., 2019). As an alternative, Bayesian inference provides solutions with clearer interpretations based on probabilities obtained from the data itself (Blasco, 2017 and Blasco, 2021). Instead of using *p-*

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values, it offers the possibility of inferring various features of the final estimates (e.g., contrasts between groups), such as the probability that an estimate is positive or negative, that it is relevant, or a guaranteed value with a certain probability (Blasco, 2017). However, unlike in frequentist inference in which there are friendly learning software in R (i.e, ASREML, https://vsni.co.uk/software/asreml-r), Bayesian inference programs for solving linear models are generally not beginner-friendly and do not provide the flexibility needed to obtain all these inferences as outputs. Therefore, there is a need to develop user-friendly tools that allow beginners to effectively understand and apply Bayesian inference in this full potential. potential.

B. Objectives

This project aims to promote the understanding of Bayesian inference among students of the Quantitative Genetics III course in the the Master of Animal Breeding and Genetics and Reproduction Biotechnology at UPV and to support its application in the professional field of animal breeding. To accomplish this, student outcomes and satisfaction will be assessed during the first year of implementing Bayesian inference practices using the *runRabbit* learning tool developed in the R programming language. The success of the project will be evaluated as follows:

1) Evaluate whether the program actually improves and facilitates learning and understanding of Bayesian inference.

2) Investigate whether students find *runRabbit* user-friendly to use for performing Bayesian inference and whether they will use Bayesian inference to solve for future professional challenges.

C. Resources used

Recently, Dr. Marina Martínez-Álvaro and Dr. Cristina Casto-Rebollo from the UPV developed the interactive software *runRabbit* for solving linear models using Bayesian inference, which offers highly intuitive and flexible outputs, with possibilities of estimating all types of inferences from the posterior distributions of the estimates. The software was tested by the authors during its development and is publicly available at https://github.com/VLabUPV/runRabbit. One of the aims of making *runRabbit* highly interactive was to prevent the common situation where the user simply mechanically executes the program without reasoning about the challenge (Cornejo et al., 2018).

D. Work activities

In the first year of implementing practical sessions in Bayesian Inference using R programming language, the program *runRabbit* was developed as a potential learning tool. This highly interactive program guides the user through a series of questions that must be answered to design the analysis. Subsequently, a practical session was designed in the Quantitative Genetics III course of the Master's Degree in Animal Breeding and Genetics, and Reproductive Biotechnology at UPV, in which a real quantitative genetics problem was solved using the *runRabbit* program. For this session, an explanatory manual for the program was prepared (available in the documentation attached to the program on the page https://github.com/VLabUPV/runRabbit), and a document detailing the objectives of the practical session was also provided.

The implementation of this practical session aimed students to learn how to apply Bayesian inference techniques to real problems and make evidence-based decisions. Students were asked to estimate the difference between two rabbit selection lines and the ratio between sexes in intramuscular fat using a linear model to correct for additional environmental variables that might affect the measurement (parity order in which the animal was born, season of the year when the measurement was taken, and live weight of the animal). In addition to estimating differences and ratios, they had to determine a relevant threshold above which contrasts between groups in intramuscular fat would lead to an important economic decision (e.g., to stop using one genetic line and use another or to use only males), an option implemented in the program. *RunRabbit* also forced students to distinguish between interesting effects (treatments) and uninteresting effects (noise), and also provided the ability to sample from posterior distributions to calculate probabilities (inferences) manually or through the program. In this hands-on practical exercise, students had to estimate the inferences of the posterior distributions themselves and create intuitive graphs representing the estimated probabilities (see, for example, Figure 1). The data and access to the R platform were provided. The practical session lasted 180 minutes and students had one week to submit the solved problem.

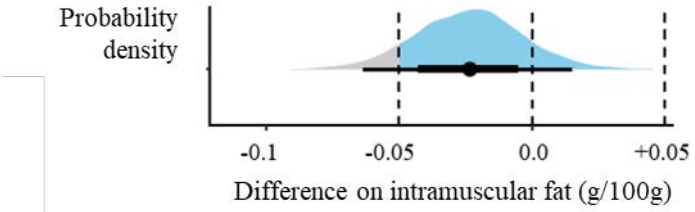

Figure 1. *Graphical output of the runRabbit program showing the posterior marginal probability distribution of the difference between lines in intramuscular fat. Assuming a relevant difference value of 0.05 g per 100g of meat, the probability of similarity is represented in blue and the probability of relevance in grey.*

Likewise, at the end of the course and after the completion of the practice, an evaluation of the implementation of the software was conducted through a survey among the students (Table 1).

Table 1. *Evaluation survey given to the students who completed the challenge*

Evaluated Aspect	Questionnaire	Answers
Evaluation of the program as a learning tool	Has using the *runRabbit* program been easy for you?	Very easy Easy Neither easy nor difficult Difficult Very Difficult
	Did solving the challenge posed with the *runRabbit* software help you understand Bayesian inference?	Very much in agreement Agree Disagree Strongly disagree
	Do you think the outputs of the *runRabbit* program	Very satisfied Satisfied Dissatisfied

	(graphs, posterior distributions, and inferences) are didactic?	Very dissatisfied
Manual	Evaluate the manual for the *runRabbit* program. Does it explain the program's operation and the possibilities it offers well?	Very much in agreement Agree Disagree Strongly disagree
Implementation in new professional challenges	Would you use Bayesian Inference to solve new challenges?	Sure Likely Unlikely I do not recommend it
	Would you recommend the use of the *runRabbit* program to other people interested in learning Bayesian inference?	Sure Likely Unlikely I do not recommend it
Satisfaction	What would you improve?	Short answer
	General satisfaction with the *runRabbit* program	Very satisfied Satisfied Dissatisfied Very dissatisfied

Finally, we examined whether the bachelor's degree students had earned prior to enrolling in the master's program had an impact on the score obtained in the practical session. This analysis was formalized using Bayesian inference and fitted with the *runRabbit* program.

3. Results

A total of 14 students participated in the practical session, 6 of whom studied Biotechnology, 5 Biology, 2 Veterinary and 1 Agronomic Engineering before enrolling in the Master's Degree of Animal Breeding and Genetics, and Reproductive Biotechnology at UPV. Overall, the students were not familiar with Bayesian statistics before starting the course. Their prior knowledge of Bayesian statistics was as follows: not familiar at all (66.7%), not very familiar (25%), and somewhat familiar (8.3%). After completing the practice, the average score of the students was 9.7, and none of them received a score below 5, which is the minimum to pass the challenge. The effect of "Previous bachelor`s" was evaluated using 3 levels: Biology, Biotechnology, Other, and no relevant differences were found between groups. The largest difference was observed between Biotechnology and Other (-0.74 [-2.47, 0.83]), and its probability of relevance, assuming a relevant value of 0.5 points, was only 0.62.

The results of the evaluation survey, answered by 12 out of the 14 students, are shown in Figure 2. Students rated the *runRabbit* program as a satisfactory and user-friendly learning tool (Figure 2A): 33.3% found it very easy, 50% found it easy, and the remaining 16.7% found it neither easy nor difficult. In addition, students felt that using the *runRabbit* program to solve the proposed task facilitated their understanding of Bayesian statistics: 66.7% of the students fully agreed and 33.3% agreed, which was one of the main objectives of the project. The majority of students felt that the program outputs (graphs, posterior distributions, and inferences) were didactically useful (58.3% were very satisfied and 41.7% were satisfied). Regarding the user manual, students generally felt that it presented the possibilities offered by the program in an understandable and coherent way (75% fully agreed and 25% agreed, Figure 2B). Finally, students felt that Bayesian inference was a useful knowledge for addressing new professional challenges (Figure 2C). 91.7% of students responded that they would definitely or very likely use it again and that they would recommend *runRabbit* software as a tool to other users (75%). When asked about possible improvements we could implement, one student responded that "he would like to see an assistant teacher in the classroom so that if a student is struggling, the class does not have to be interrupted to attend to them". We will consider this in future editions. Overall satisfaction with the program was 75% very satisfied and 25% satisfied (Figure 2D).

4. Conclusions

In summary, the pilot use of the *runRabbit* software in learning Bayesian inference has resulted in an extremely positive experience for students and teachers, both in terms of learning and satisfaction. In addition, the use of this tool has helped develop a new computational thinking skill, and students have expressed a willingness to use Bayesian inference in future professional challenges. The results suggest that the *runRabbit* software can be a valuable tool for improving the teaching of Bayesian statistics, not only in the field of animal breeding, but also in any other field that requires statistical analysis of data. However, we are aware that our sample size is limited. To confirm these results, *runRabbit* will be tested in larger groups in the coming years.

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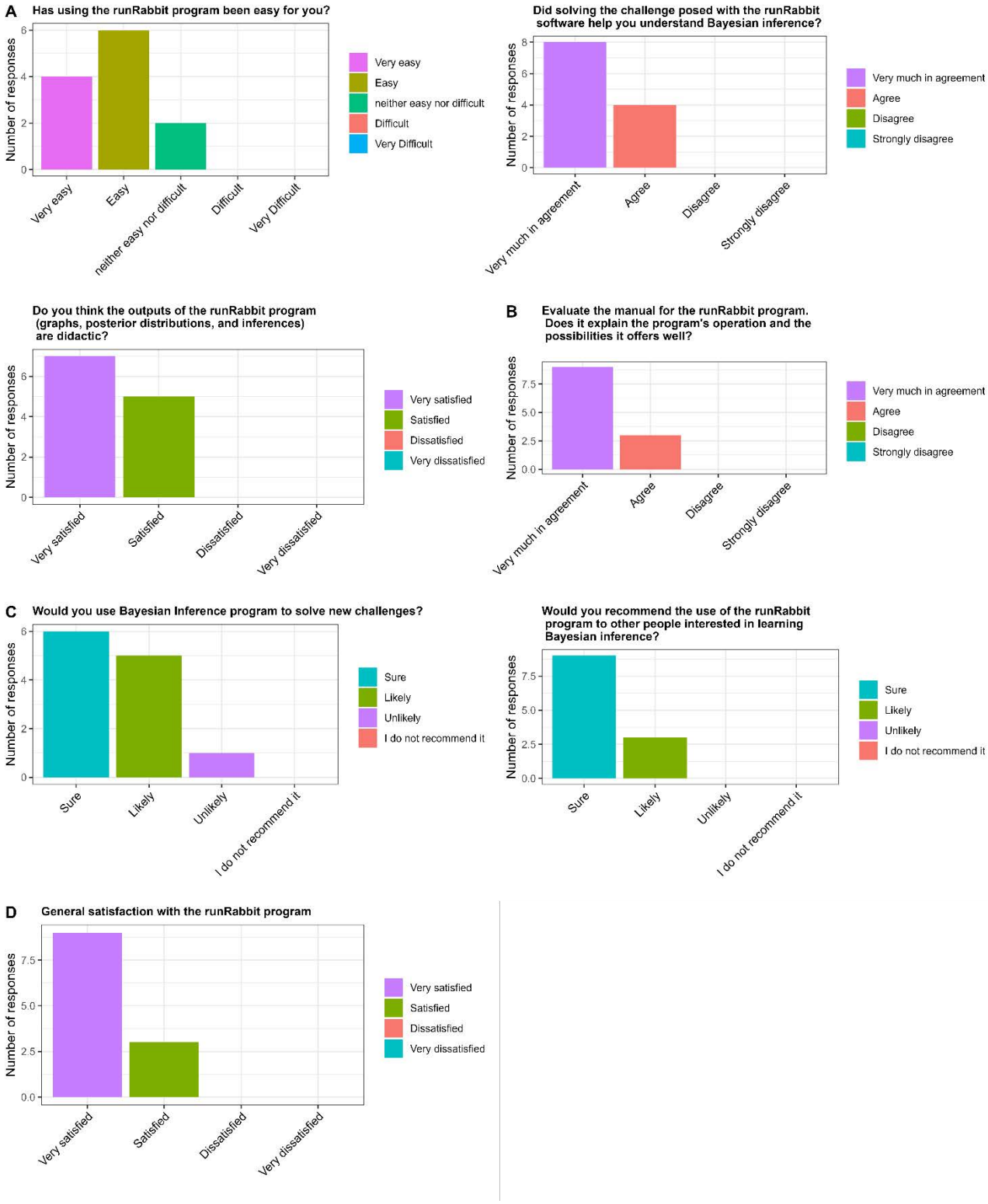

Figure 2. *Results of the evaluation surveys for the runRabbit program.* ***A.*** *Questions aiming to evaluate the program as a learning tool.* ***B.*** *Question to evaluate the manual.* ***C****. Questions to evaluate whether users will implement the program in new professional challenges.* ***D.*** *Questions to evaluate the overall satisfaction.*