Pedagogical and iterative design of a serious game for statistical literacy: Enhancing player experience for college students by developing version 2.0

Abstract: Learning statistical concepts, such as measures of central tendency, are foundational for understanding data analysis and interpretation. However, students often struggle with their comprehension and application. In order to try to facilitate and improve its learning for college students, making it more viewable, interactive and fun, we have created the digital serious game *"To be indicated to respect blind peer review"*.

In this paper we present the iterative redesign and implementation of the second version of this serious game, developed in response to feedback from 56 pre-service teachers (undergraduate and master's students) who tested version 1.0. Building on constructivist principles, version 2.0 introduces three key player experience improvements: better interaction with elements, user-selectable levels and more step-by-step guidance. Although this new game version has not yet been tested, we hope that the commented improvements implemented in this new game version 2.0 will enhance the gameplay experience and may help other serious game designers and developers to create better experiences from the start, allowing students to focus more on the learning contents than on issues related to the game's interface.

Keywords: Serious games, Mathematics, Statistical education, Player experience.

Introduction

Students face different problems when learning mathematical concepts, due to its perceived complexity or its abstract nature. Specifically, when studying introductory statistical concepts, they experience various challenges and concerns such as the need to deal with complex formulas that put them under pressure and make them difficult to understand the learning contents (Mohamed et al., 2012), the feeling of not having the necessary competence to learn these concepts, low motivation, the limited usefulness of statistics in the real world (Sutter et al., 2023), conceptual incomprehension (Said and Siew, 2019), or the need to deal with complex formulas that pressure them and hinder their understanding of the learning content (Mohamed et al., 2012). Moreover, the study published by Widyastuti et al. (2019) indicates that motivation is a key factor for university students to be able to understand statistical concepts.

On the other hand, serious games (SGs) are a powerful tool for student learning and motivation (Connolly et al., 2012) and they represent a resource widely spread for pedagogical purposes (Paciarotti et al., 2021). However, the software used must be adapted to the specific curriculum required so that it meets the learning content that must be taught and learned for a given level and subject area (Fraga-Varela, P., 2021).

SGs are games whose primary purpose is beyond entertainment, such as education, training, healthcare, or social change (Michael & Chen, 2006). The term "serious game" was introduced for the first time in 1970 by Clark Abt, defining them as structured activities designed to educate or train while retaining elements of fun (Abt, 1987). They should always seek a balance between teaching knowledge and fun (Laamarti et al., 2014).

SGs can be, depending on the format in which they are presented, analogue, when they are carried out using physical materials; or virtual or digital, when implemented through video games. Digital SGs incorporate technology to create interactive environments that enhance learning and engagement. They aim to teach specific skills, reinforce knowledge, or influence behavior while maintaining the enjoyment of gameplay.

In order to try to facilitate the learning of statistical concepts, in particular, the underlying concepts of distributional graphs and understanding and calculating measures of central tendency -mean, median, and mode- for college students and, in particular, for university-level pre-service teachers (undergraduate and master's Education students), we have created a SG called *"To be indicated to respect blind peer review".*

In the following section, we introduce the pedagogical design of this statistical-related SG, a brief summary of the feedback received when applying a 1.0 version to a sample of 56 out of 146 education students (17 out of 50 from first year of a degree in primary education teaching, and 39 out of 96 students from a master's degree in secondary education, high school and vocational training) and the improvements included in the design and implementation of a 2.0 version. Finally, we conclude with several observations and lessons learnt of iterating the design of SGs to create better game player experiences from the start.

A digital SG for learning statistical distributions and central tendency measures

Based on constructivism theory, where the learning has a student-centered approach and knowledge is constructed through its application (Bada, 2015), the digital developed SG on mathematical statistics aims to instruct in concepts about distributional graphs and measures of central tendency in statistical distributions (mean, median and mode), so that after the explanation of an idea or concept, the player can put into practice its application.

These concepts of statistical distributions and measures of central tendency are often part of different levels of mathematics curricula, so it is a content that can be applied and/or can be served as a basis for the teaching and learning process of various mathematical subjects, both for primary and secondary education levels, as well as for university levels, depending on the depth of the complexity and formulas concerning the subject.

Regarding the design of the game, it is made up of two parts: a first part that acts as a tutorial to learn basic concepts of statistics and how to play the game, and a second part, the game itself, which aims to deepen into the concepts seen during the game tutorial. Based on our previous experience in the design and evaluation of other SGs versions, we established that the tutorial should be mandatory, since we have verified after evaluating previous SGs that students achieve better performance during the game when the tutorial is compulsory to play the game (Reference not included to respect blind review).

In regard to the learning contents on which the SG is based on, it consists of two main exercises: one group to learn what statistical frequency distributions represent , through understanding their construction, as it is shown in Figure 1, and another group to learn how to calculate the measures of central tendency of a distribution- mean, median and mode- with the help of a calculator, as it can be seen in Figure 2. Both groups of exercises incorporate a help section with its associated formula.

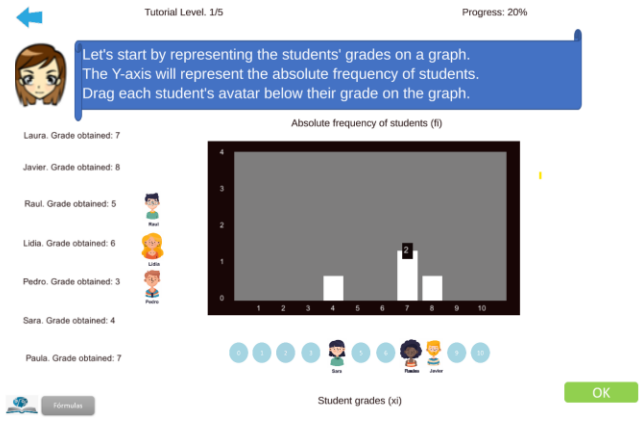

Figure 1. Example of game screenshot with exercise to represent frequency distributions. Students must drag and drop specific individuals that represent the values from the associated frequency distribution graph.

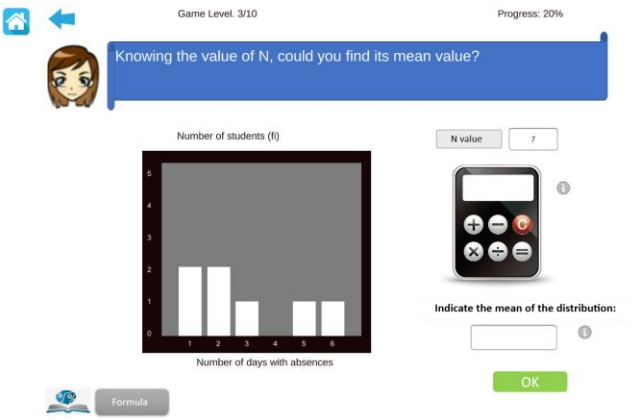

Figure 2. Example of game screenshot with exercise to calculate the mean from a distribution graph. In-built calculator in v.1.0 of the game allows the operation with it by entering values using the keyboard.

The game was developed using the Unity game creation platform. The reason for this choice was that it is a free and cross-platform game development tool, and the learning curve required for game creation is more gradual than with other similar tools.

As for the game's design, we've tried to create a simple interface, including the most relevant graphic elements, so that it allows players to concentrate on the requested activities without losing focus.

Feedback received from v.1.0 and game version improvements developed in v.2.0

After carrying out the application of version 1.0 of the SG with 56 out of 146 education students, 17 out of 50 from the teaching degree and 39 out of 96 from the master's degree in teacher education in secondary education, baccalaureate and vocational training, and by using various surveys and satisfaction questionnaires, we observed the need to make a series of improvements to enhance the gaming experience and its interactivity.

Although the game managed to improve statistical knowledge slightly (pre-test mean: 7.71 points, post-test mean: 8.07 points, increase: 0.36 points) and managed to keep students highly engaged and motivated by practicing statistical learning contents, many students (7.1%) reported having difficulty using the calculator, as they found calculations tedious and cumbersome; 7.1% of students also commented that the game's music distracted them and made them lose focus; another percentage of students (3.6%) reported not easily finding the help they needed to continue advancing in the game and became blocked in some exercise cases, and the similar percentage of students (3.6%) suggested that there should be more levels.

Thus, version 2.0 introduces three key pedagogical design improvements:

- Better interaction with elements: In order to make the calculator easier to use and more useful, when clicking on the axes and values of the distribution graphs, the values are transcribed into the calculator's values field, allowing direct interaction with these values, which improves the calculator's usability and simplicity.
- User-selectable levels: Although version 1.0 included different levels of play, to reach game level 3, for instance, one had first to go through levels 1 and 2. So that more experienced users can skip levels after completing the mandatory tutorial, version 2.0 has implemented two levels, basic and advanced (see Figure 3), so that players can select the level they want to try to complete, based on their estimated skills after having completed the tutorial part.
- More step-by-step guidance: To address the issue of getting stuck on exercises, more step-by-step help has been added at the beginning of each exercise in the tutorial section and during gameplay in easy mode, as shown in Figure 4. Additionally, depending on the level of the game we are at, only certain click elements will be enabled to further guide learning.

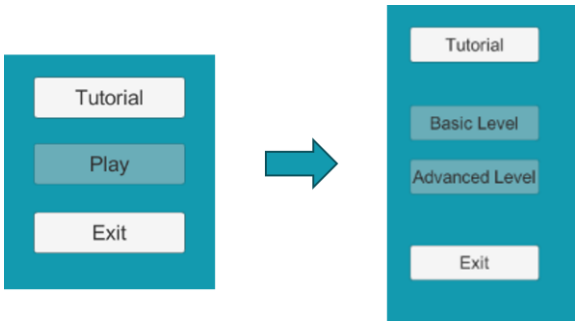

Figure 3. User selectable levels' improvement from v.1.0 to v.2.0

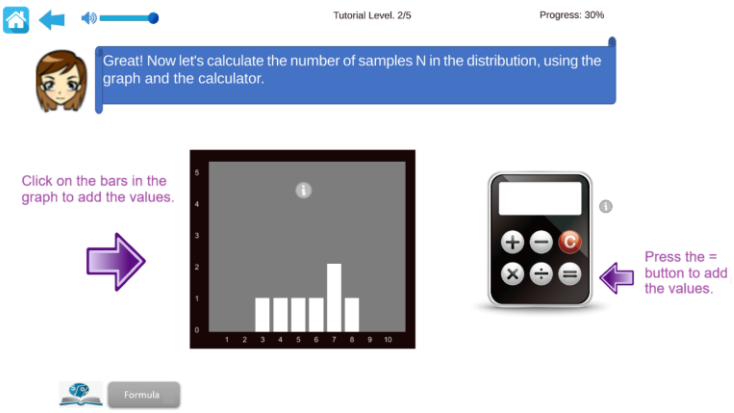

Figure 4. Example of game screen of the tutorial including more step-by-step exercise guidance.

Other improvements implemented included adding a volume bar to the game's music, so that not only can the music be turned off, but it can also be kept on allowing players to concentrate better, as well as escape points within the game to return to the home screen in case they get stuck or blocked at some point in the game.

Conclusions, limitations and lessons learnt of iterating the SGs design

Although this new version of the SG has not yet been tested, we hope that the commented improvements implemented in this new 2.0 version will enhance the gameplay experience, improving student results, not only academically but also affective, compared to using version 1.0. In any case, this version will need to be validated first to verify that it meets expectations.

Regarding the limitations of this new game design version and implementation, there's still room for further improvements, such as a greater number of game levels, greater complexity in subsequent levels, more gamification elements, such as a fictional narrative thread or new game dynamics, that would extend the game and enrich the experience, or saving game options so that players can close the game and continue later from the point the player left off.

According to the iteration in the design of SG in order to create better experiences from the start, it is worth considering several ideas: on the one hand, players like to feel in control of the game, so it is recommended that they are able to choose certain aspects during the game. In the particular case of SGs, where the key focus is the learning contents or the skills training, it is desirable for players to have the power to select the game level according to their own criteria, so they feel in control of their learning pace. Besides, it is also necessary that their motivation during the game does not decline due to a perceived feeling of lack of competence, so it is advisable to carry out very guided learning paths from the beginning.

On the other hand, as it is an SG, we must not forget to start its design by establishing the desirable learning objectives and course contents to develop a game that facilitates its achievement. In addition, it is convenient to present the contents in the most visual and interactive way possible; in the particular case of mathematics, this translates to use of graphs and representations such as bar charts, pie charts, scatter plots, or distribution functions, enabling students to better understand and assimilate the underlying data (Meletiou et al., 2019), and it is also recommendable to work through them on mathematical practical problem cases (Westera et al., 2014; Wronowski et al., 2020) to train analysis, inquiry and decision-making skills.

In terms of game development, it is advisable to introduce "escape" points into the game, from which players can return to the beginning if they get stuck; saving-game options so players can close the game and continue from the point where they left off; or a volume bar for the music, that allows to complete tasks without losing focus.

By implementing these game design improvements and recommendations, we hope to greatly increase the effectiveness and gameplay experience of our SGs, increasing its interactivity and improving the achievement of the desired learning objectives, without forgetting key aspects such as engagement and enjoyment.

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