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A linear algebra quiz game as a supplementary learning tool in tertiary-level

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ABSTRACT

This article presents a study investigating the use of games in undergraduate mathematics instruction, with a specific focus on students' perspectives regarding post-instructional quiz games. The study explores students' opinions on the implementation of a linear algebra quiz game as a supplementary learning tool. A survey was administered to 78 students to examine their perceptions of the game's usefulness in preparing for their linear algebra examinations. Students reported high levels of attention and interest while engaging with the game and described it as fun, dynamic, exciting, and beneficial for reviewing linear algebra concepts. The findings suggest that quiz games can be a valuable addition to undergraduate mathematics education, fostering student engagement and providing an enjoyable and effective means for reinforcing course material.

Keywords: mathematical games, quiz game, students' perceptions, undergraduate students, linear algebra

INTRODUCTION

There has been and continues to be a plethora of teachers and researchers enthusiastic about the use of games in the teaching and learning of mathematics (González Peralta et al., 2014; Mousoulides & Sriraman, 2020). There are teachers who claim that the use of games in the mathematics classroom captures students' attention and promotes their learning. Whether through technology-enhanced games or analog games, the use of games in the teaching and learning of mathematics is a clear trend in mathematics education research. However, most of this research and practical experience accumulated over the years has focused on the use of games for teaching mathematics to children and adolescents. There are very few research studies developed on the use of games at the university level (e.g., Afari et al., 2012; Cornock, 2015; Rowlett, 2019). It seems that the enthusiasm for the use of games in the learning and teaching of mathematics is concentrated in the basic levels of instruction, and that it wanes as one progresses to higher educational levels. A possible explanation for this is that some people consider that the use of games does not correspond to the more serious mathematics studied at higher educational levels.

But what do the students think? How do they feel about using games at the undergraduate level? Exploring students' perspectives is one way to investigate the relevance of using games at this educational level.

Bright et al. (1985) point out that an instructional game is one for which a set of educational, cognitive or affective aims have been established. Oldfield (1991) in turn defines a mathematical game as an activity governed by a set of rules that represents a challenge against a task or against one or more opponents. This challenge can be faced individually or in teams and must pursue specific mathematical cognitive objectives.

The study reported in this paper investigates the use of games in mathematics instruction at the undergraduate level. In particular, it focuses on mathematics students' perspectives on the use of post-instructional games, by exploring their opinions associated with the use of a quiz game as a practice for their linear algebra tests. According to the Merriam-Webster (2023) dictionary, a quiz game is: "a form of entertainment often used on radio or television in which the members of a panel compete in answering questions".

This study is focused on a quiz game. There is evidence suggesting that this type of game motivates and produces a high level of engagement among the students, favoring an environment in which they argue and justify their mathematical solutions before agreeing on an answer (Afari et al., 2012). On the other hand, it has been shown that students who take practice tests often outperform students in non-testing learning conditions such as restudying, practice or filler activities (Adesope et al., 2017). Thus,

this study addresses the following research question: *What perceptions do students express regarding the usefulness of a quiz game as a practice for their linear algebra examinations?*

The research study reported in this paper contributes to broadening our understanding on the use of games as a study strategy in mathematics for college-level students. To place this study in the research landscape, in the next section we offer an overview of research on the use of games in mathematics education.

USE OF GAMES FOR TEACHING & LEARNING OF MATHEMATICS

The use of games for the teaching and learning of mathematics has been promoted for decades by different agents of mathematics education: from mathematics teachers who consider that games can be perceived as fun by students–thus favoring their engagement in the study of mathematics, to psychologists and mathematicians who suggest that games have a very important role in learning, particularly in the learning of mathematics (Ernest, 1986). In this section we offer an overview of the research on the use of games in the teaching and learning of mathematics.

Research on Use of Games for Teaching & Learning of Mathematics

The 1970s saw a growth in mathematical analyzes of games and puzzles (e.g., Gardner, 1970) but there was also an emergence of empirical studies on the use of games for the learning of mathematics (see for example Allen et al., 1978; McCann, 1977). This observation is confirmed in the monograph on learning and mathematical games by Bright et al. (1985), which illustrates that during the two decades prior to its publication, there was a significant increase in the number of studies on mathematical games. During subsequent years, several studies were developed on the use of analog games in the teaching of mathematics. For instance, the classic "race to 20" game (Brousseau, 2002) used to revisit the concept of division and foster the discovery and demonstration of theorems by children; the use of chess as a teaching tool to promote mathematical problem solving skills among elementary school students (Kakoma & Giannakopoulos, 2016); or the use of board games to promote the understanding of integers among kindergarteners and first graders (Bofferding & Hoffman, 2019), among others.

In recent years, interest in the use of games for the teaching and learning of mathematics has enjoyed a renewed enthusiasm. This is fueled by the use of digital technologies, which have diversified the possibilities and enhanced the potential of games in mathematics education (e.g., Lowrie & Jorgensen [Zevenbergen], 2015). Thus, nowadays it is possible to find several studies on the use of digital games for the teaching and learning of mathematics (e.g., Ke & Clark, 2020; Rosa & Lerman, 2011; Soldano & Arzarello, 2016; Wijers et al., 2010).

For years, scholars have advocated using games to teach linear algebra (e.g., Graham-Squire et al., 2014). However, in recent years, there have been more reports of using playful activities to enhance the learning of linear algebra at the university level, particularly in engineering education. In 2019, Mauntel et al. (2019) presented the results of a study based on a game called "vector unknown" whose purpose was to support students in learning using both algebraic and geometric approaches. Abdul Rahim et al. (2020) discuss the effectiveness of gamification with storytelling to enhance the learning of linear algebra. The authors consider students' responses to a pre-test and a post-test for the study. In the same year, Queiruga-Dios et al. (2020) proposed an activity based on a "breakout" or "escape room" game, where a simulation is conducted in which students must find a key to open a locked box or escape from a room. Through riddles, problems, and some clues, the aim is for engineering students to learn not only about linear algebra but also about calculus or cryptography. But what are the main benefits that are obtained through the use of games in mathematics teaching and learning?

Benefits of Use of Games for Teaching & Learning of Mathematics

Over the years practitioners and researchers have reported different benefits of integrating the use of games in the teaching and learning of mathematics. For instance, Ernest (1986) claims that the use of games can help to achieve three of the aims of mathematics teaching: gain new concepts and develop them, practice and reinforce skills, and develop problem-solving strategies. Ernest (1986) also acknowledges the affective value of the use of games in mathematics instruction:

> This is the first and most striking advantage of introducing games into the mathematics classroom. Pupils become strongly motivated, they immerse themselves in the activity, and over a period of time should enhance their attitude towards the subject (p. 2).

One of the aspects that the study reported in this paper emphasizes is the perception that students have about the usefulness that a quiz game as a practice for their linear algebra exams can have. As mentioned before, there is research suggesting that the use of quiz games in mathematics can produce high levels of engagement among the students, favoring an environment in which they argue and justify their mathematical solutions (Afari et al., 2012). We consider that the emphasis of the study reported here contributes to adding students' voices to this discussion about the usefulness of the use of games in the teaching and learning of mathematics.

METHOD

Students Participating in the Study Session

The study was developed in a public university located in the north-west of Mexico. The study participants were 78 undergraduate students who were majoring in applied mathematics, physics and computer sciences. At the time of participating in the study, all the students were enrolled in the second semester of their university studies. The ages of the participants ranged from 17 to 32 years (where 90% of the participants were 21 years old or younger). 60 participants are male, and 18 participants are female. The students gave their verbal consent to participate in the research as long as their anonymity was preserved.

Description of Quiz Game & Its Implementation

The quiz game used in this study addresses introductory content to linear algebra such as systems of linear equations, matrices and determinants. This practice is presented to the students in the form of a quiz game to make it more dynamic and engaging for the students, but also to favor and immediate feedback about the mathematical contents addressed. According to the definition of Bright et al. (1985), this activity can be considered an instructional game since it pursues a specific educational aim–in this case, the review of linear algebra contents. In addition, as Oldfield (1991) points out, in this mathematical game the players face a series of mathematical tasks posed as questions, which they must answer according to the set of rules established at the beginning of the game. This activity can also be classified as a quiz game because it promotes a competition that is based on answering correctly mathematical questions. The features of the game are presented in more detail below.

In a PowerPoint presentation 70 questions are posed–one question per slide. The approximate duration of the activity is 90 minutes, which is the official time available for a full lesson. The questions posed require students to remember definitions and properties of the concepts addressed and, in some cases, to justify their answer. Examples of the questions included in this activity are the following:

- Define the concept of upper triangular matrix.
- Determine if matrix $B = \begin{bmatrix} 6 & 4 & 6 \\ 1 & 2 & 1 \\ 3 & -1 & 3 \end{bmatrix}$ is a symmetric matrix and explain why.
- Given a pair of invertible matrices *A* and *B*, is it true that $(AB)^{-1} = A^{-1}B^{-1}$? Justify your answer.
- Given a square matrix *A*, what condition must the determinant of *A* satisfy in order for matrix *A* to be invertible?
- Given a matrix *C* of dimension three, if det *C*=5, what is the value of det 2*C*?
- A homogeneous system of linear equations will always be consistent. True or false? Explain.

In addition to the PowerPoint presentation, the teacher uses a deck of cards with all the students' names and a list to record their answers. The dynamics of the activity is, as follows: A student volunteer draws a card from the deck. The name written on the card corresponds to the student who will answer the first question. Once the first participant has been chosen, the question is projected, the teacher reads it aloud, and the first participant provides an answer. In the list it is recorded whether the answer is correct or incorrect. The card with the first participant's name is returned to the deck, and this first participant draws another card to determine who should answer the next question. The random choice with replacement aims to foster students' interest in the quiz game, thus, the process continues until all the questions have been answered.

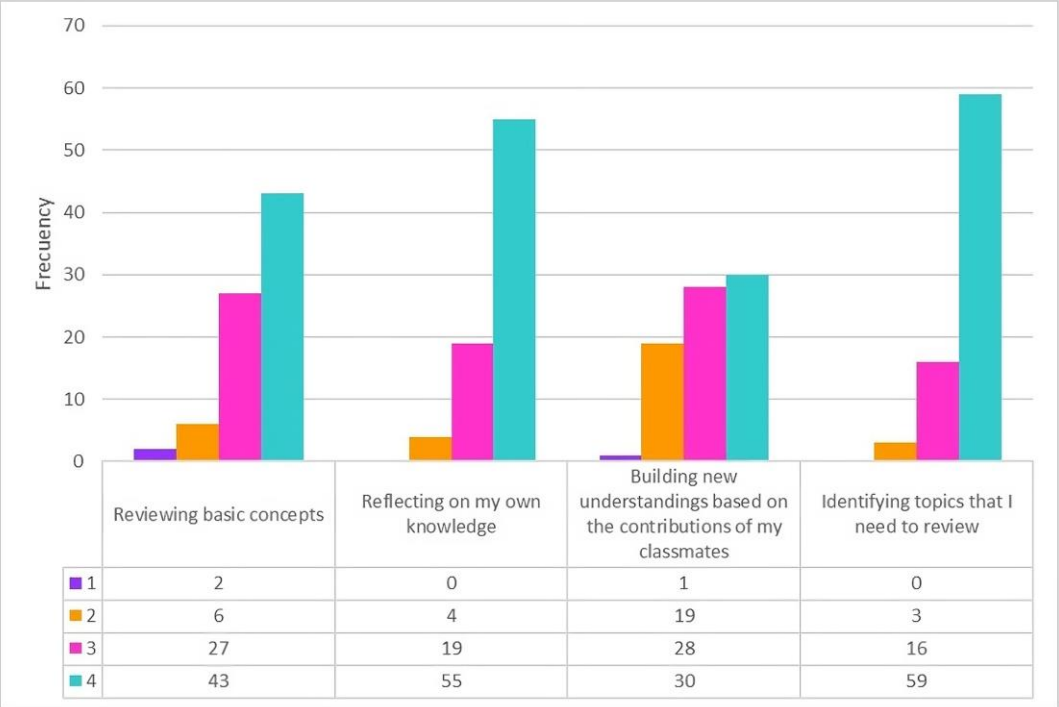
To enrich the game dynamics, there are five wildcards. If a student gets a wildcard, a success is recorded for this student without the need to answer any questions, and the game continues normally and, if a participant draws the card with their own name, the game continues in the usual way. This is, they must answer the question and then draw another card. There is no limit to the number of questions that each participant must answer. The number of times a student must answer depends on chance.

To favor the review of contents the questions are arranged in the same order in which the topics were studied in class. Students are invited to pay attention to their classmates' answers since they may be relevant to the next question. For instance, a slide might ask the definition of the trace of a matrix, and in the next slide might ask to calculate the trace of a given matrix. Moreover, if a participant provides an incorrect answer or does not answer the question, the question remains open for the next selected student. If after three turns the question has not been answered correctly, the students in the audience can raise their hands and try to answer. Those with a higher error rate are given priority to give them a chance to recover.

Survey & Data Analysis

To collect evidence of students' perceptions about the usefulness of this quiz game to prepare themselves for their linear algebra exams, a survey with six items was designed. To assess the pertinence, coherence and relevance of each of the items, a group of four researchers in mathematics education were asked to carry out an individual review of the items. Based on their recommendations and criticisms, a revised version of the instrument was prepared and applied to the group of students who participated in the study session, where this teaching strategy was implemented.

The issues that are explored with this instrument can be categorized into two large groups what usefulness the students attribute to the quiz game (if any) and what differences they perceive in comparison with similar practice activities (for instance, a practice test but in a written format). The quiz game was carried out in a single session, and the instrument was applied in the next day's session, this due to the duration of the lesson. They were asked to answer the instrument anonymously to encourage the participants to express their opinions freely. The students responded in writing to the survey. Once the instrument was applied and answered, the students' responses were transcribed and captured in an Excel spreadsheet for later analysis.



	Reviewing basic concepts	Reflecting on my own knowledge	Building new understandings based on the contributions of my classmates	Identifying topics that I need to review
1	2	0	1	0
2	6	4	19	3
3	27	19	28	16
4	43	55	30	59

Figure 1. Frequencies for four indicators through students rated usefulness of quiz game (Source: Authors' own elaboration)

RESULTS: WHAT PERCEPTIONS DO STUDENTS EXPRESS REGARDING ACADEMIC USEFULNESS OF QUIZ GAME?

Students were asked to rate, on a scale of one to four, the usefulness of the quiz game to help them with:

(a) reviewing basic concepts of linear algebra,

(b) reflecting on their own knowledge,

(c) building new understandings based on the contributions of their peers, and

(d) identifying topics that need to be reviewed.

In this case, one represents "not at all useful", two represents "slightly useful", three represents "useful", and four represents "very useful". The frequencies of the students' responses are shown in **Figure 1**.

The level of utility attributed to each of these four aspects is very positive. As shown in **Figure 1**, the highest frequency in the four indicators is at level 4 of the scale. Likewise, the median for the categories "reviewing basic concepts", "reflecting on my own knowledge", and "identifying topics that need I need to review" is four. The category "building new understandings based on the contribution of my classmates" has a median of three. It can be seen that students' assessment of the usefulness of this quiz game is positive. In particular, it is perceived as useful to reveal knowledge gaps and to generate a reflection on their own learning.

To further deepen students' opinions, they were asked to indicate if they would recommend that this activity be applied in other courses of their study program. Given this, two participants did not provide a response, four replied that they would not recommend the activity, and the rest answered that they would recommend it. In addition, the participants were asked what they would prefer if they could choose:

(1) to participate in a quiz game like this one again,

(2) to answer all the questions in writing, or

(3) either of the two options; they were asked to explain their choice.

39 students indicated that they would prefer to participate in this kind of quiz game again, 10 would prefer to answer the questions in writing, and 29 indicated that either of the two options would be good for them.

Those who answered that they would prefer to respond in writing argue two main reasons for this: to avoid the stress generated by responding in front of the whole class, and to have more time to reflect on their potential answers. The following responses illustrate these arguments:

- "When your classmates are listening to you, it makes you more nervous and there is time pressure. All together makes you doubt."
- "Because I like to think carefully about my answers and thoroughly visualize what I need to answer."

The reasons given by those who would choose to participate in the quiz game again emphasize that the activity was fun for them, in addition to valuing immediate feedback and group learning. They also mentioned that they felt more motivated to pay attention and learn from their peers. This is illustrated below with transcripts of some of their responses:

- "I think it is good to change the dynamics of the activities, by stimulating creativity in an environment in which you do not necessarily do a written exam in complete silence as usual."
- "I found it very funny, despite all my nerves I learned a lot from my classmates."
- "It's more exciting, you end up happy no matter how it went. It is also a more interesting activity, here we can laugh, get excited and lament in a collective way."
- "It is much more interesting than a written test, I studied more for this activity than I would have studied for a regular test."

Finally, the reasons provided by those students who indicated that either of the two options fit them, tend to reflect their perceptions of the pros and cons of the activity. For instance,

- "In the activity that was carried out, more nerves were felt but more attention was paid to it."
- "Although it is unusual and you have more emotions and feelings as well as critical states of mind, it was entertaining and a good review."
- "It is an activity that becomes fun within the group. In an exam I would have less nerves, but the activity helps to better review the topics."
- "In a written exam you have more time to reflect on your answer, but in this activity the advantage is that you can recognize sooner if you know or not, so I can focus more on those topics."

Considering the opinions expressed by the students regarding the quiz game, and based on the results presented, the research questions is answered next. Moreover, elements that allow deepening the conclusions derived from this study are established.

CONCLUDING DISCUSSION

In relation to the research question, "what perceptions do students express regarding the usefulness of a quiz game as a practice test for their linear algebra examinations?", students express positive perceptions regarding the usefulness of the quiz game as a practice test for their linear algebra examinations. They characterize the quiz game as fun, dynamic, and exciting, which aligns with previous findings that suggest quiz games can motivate and engage students in a learning environment (see for example Afari et al., 2012). Additionally, the high levels of attention and interest reported by the students–with a median score of gour on a scale of one to four–suggest that the engaging nature of the quiz game can potentially enhance students' mathematical learning experiences. Furthermore, students acknowledged that the quiz game helped them identify their knowledge gaps, reinforce their understanding of linear algebra concepts, and learn from the contributions of their peers. These perceptions indicate that the quiz game is not only enjoyable but also valuable for their learning process. Overall, students view the quiz game as a useful tool for preparing for their linear algebra exams, suggesting that such games can be an effective and engaging pedagogical approach in undergraduate mathematics education.

This study has investigated undergraduate students' perspectives on the use of a quiz game as a practice test for linear algebra, providing valuable insights into the feasibility and effectiveness of such games in a university setting. The findings contribute to the growing body of research on the use of games in tertiary mathematics education and extend our understanding of the potential benefits and levels of acceptance of such games among undergraduate students. The conclusions drawn from this study suggest that implementing quiz games in undergraduate mathematics education is not only feasible but also potentially beneficial for students' study processes, motivation, and engagement. The quiz game format fosters group learning, allowing students to become more aware of their strengths and knowledge gaps in linear algebra. Furthermore, hearing their peers' responses to mathematical questions highlights the value of collaborative learning in this context.

However, further research is needed to explore the full extent of the potential benefits of using games in undergraduate mathematics education. While this study provides evidence supporting the positive impact of quiz games on engagement, motivation, and study processes, future research could focus on determining whether games can promote the development of other mathematical competencies among university students. The existing literature points to various benefits of using games in mathematics education, such as improved motivation and attitudes, the development of problem-solving strategies, skill reinforcement, and knowledge construction. However, whether these benefits extend to undergraduate students remains an open question that warrants further empirical investigation. By exploring these and other potential advantages of game-based teaching approaches, the academic community can develop a more comprehensive understanding of the role games can play in enhancing undergraduate mathematics education.

Moreover, it would be beneficial to examine the long-term effects of using quiz games as a pedagogical tool in undergraduate mathematics education. Future studies could investigate whether students' positive perceptions and engagement with quiz games translate to improved academic performance and retention of mathematical concepts over time. Additionally, researchers may explore how the integration of quiz games into the curriculum could affect students' attitudes towards mathematics and whether it can contribute to reducing mathematical anxiety, a prevalent issue among students at all educational levels (Warwick, 2017). Furthermore, to better understand the generalizability of the findings, future research could involve larger and more diverse samples of students, as well as a broader range of mathematical topics and contexts. This would allow for a more comprehensive

understanding of the effectiveness of quiz games and other game-based learning approaches in various mathematical domains and different educational settings.

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