Game-based Learning for Science Education in Institutional Care Settings in Northwestern Mexico

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Abstract: Play has been key to knowledge acquisition, creativity, and innovation. In education, game-based learning (GBL) is a physical and digital environment that enhances learning outcomes in students. This paper presents the results of observational research on game-based learning in science education as a motivation for young students from two institutional care settings in Northwestern Mexico, in the State of Sonora. The observational research touched on 1) game-based learning in science, technology, engineering, and mathematics (STEM) education, and 2) learning motivation in vulnerable student groups. This paper focuses on the authors' experiences, most of them early researchers focused on science education, their purpose of promoting game-based learning in STEM education, and interviews with representatives from both institutions. We found that game-based learning was seen as a novelty, innovative, and motivational way of engaging young students from institutional care settings to learn and become curious about the STEM field. We also designed and created games focused on STEM subjects in both institutions. Students living in institutional care settings face even greater obstacles regarding education. In some instances, the lack of mentorship or follow-up tutoring activities can determine their academic outcome or lack thereof. With the ever-changing world of technology, industries demand highly qualified people in STEM fields. Nonetheless, international organizations such as the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the Organisation for Economic Co-operation and Development (OECD) have reported that school systems around the world are not equipped with the proper teaching methodologies for students to acquire basic skills such as mathematics nor critical thinking. In Mexico, public school systems and institutional care settings often lack teacher training or mentorship approaches to promote STEM education. This paper concludes with a reflection on the benefits of GBL in STEM education in such settings and suggestions for student-led collaborations with children and youth in such settings.

Keywords: Educational Innovation; Game-based Learning; Higher Education; STEM Education; Tec 21 Educative Model.

1. Introduction

Teaching science, technology, engineering, and mathematics (STEM) disciplines can be an obstacle for some educators. In students, there is a motivation gap between STEM subjects in lower academic grades and higher education enrollment. Some studies have mentioned that a lack of interest or engagement in such disciplines occurs in students which can be difficult to reverse. Therefore, different educational approaches should be used when engaging students with STEM education.

In 2023, the World Economic Forum noted that STEM industries worldwide need human capital with the proper credentials and knowledge. Nonetheless, “many countries have tried to bolster enrollment in STEM to aid important growth industries like medtech, digital services, mobility or computer sciences. However, countries have had varying success in the matter”. In a study, Yan, Yu & Chen (2024) noted that “ China boasts the largest number of STEM graduates in the world, and the number of STEM graduates is increasing every year as China's higher education becomes more accessible. [Nonetheless], the percentage of traditional engineering graduates has declined in recent years'' (p. 397)

According to Arztmann, Hornstra, Jeuring & Kester (2023), students from low socioeconomic backgrounds need greater motivation when engaging with STEM education and at an early age. The authors note that “games should be implemented early on to be most effective, particularly to improve students' motivation for STEM subjects which might help to intervene with the general decrease of interest in these subjects later on” (p. 132).

This decrease is highly notable in the number of women deciding on a STEM career. The United Nations Educational, Scientific and Cultural Organization (UNESCO) mentioned in their Global Education Monitoring Report 2024, Gender Report: Technology on Her Terms that women “are particularly underrepresented in science, technology, engineering and mathematics (STEAM) education - women make up only 35% of STEM graduates, a figure unchanged in ten years - and consequently, in STEM careers” (UNESCO, 2024).

The United Nations has reported that 6 out of 10 children and adolescents do not reach the minimum level of critical thinking skills; and that "by including methodologies in the learning process that aim to motivate and engage student learning, such SDG can be achieved by 2030 with the aid of professors and institutions alike" (Olivas, Velázquez & Duarte, 2023, p. 351).

The different factors impacting young learners during their formative years are only enhanced in difficult socioeconomic situations and family dynamics. Furthermore, the lack of representation among ethnic and gender minorities in STEM fields, as indicated by a National Science Foundation (NSF) analysis spanning from 2006 to 2016, stands as a contributor to the dwindling motivation among schoolchildren. To encourage interest and curiosity among these groups, additional educational tools should be implemented when teaching STEM education (Strayhorn, 2013).

Education should aid in eliminating these disparities. Gender inequality, lack of representation, and receding motivation and accessibility for children to pursue a place in the STEM workforce are present globally. In the case of Mexico, the Organisation for Economic Co-operation and Development (OECD) reported that it has one of the lowest school enrollment rates among 15 to 19-year-olds (OECD, 2014). Both public and private sectors must collaborate in igniting interest in fields such as engineering, biology, and applied mathematics. It is paramount for both to collaborate and design programs, such as those involving game-based learning, to lessen the impact of gender gaps, and lack of representation for minorities, and to encourage young boys and teenagers in institutional care settings to become involved in the STEM fields.

Game-based learning studies are mostly focused on its performance in educational institution settings (Wernet & Benjamin, 2023; Juric, Bakaric & Matetic, 2021; Ameerbakhsh, Maharaj, Hussain & McAdams, 2019). However, afterschool programs, community clubs, organizations, or other types of institutional settings also offer educational programs that enhance and promote STEM activities among young learners. Oftentimes, these other settings allow learners to receive a more personalized learning experience since the number of participants in them is on the smaller end.

This paper is intended to focus on the authors' experiences as volunteers in STEM activities in an institutional care setting in the Northwestern region of the State of Sonora, Mexico, and how game-based learning can aid in promoting and encouraging young learning in such fields. This is to analyze how game-based learning can aid young learners in specific contexts. The paper explored how early contact with activities and game-based learning can encourage learners to know more about STEM and become involved in these fields.

1.1 Game-based Learning in STEM

Studies have shown that "game-based learning has drawn international interest and has been reported as an effective educational method that can improve students' motivation and performance" (Stohlmann, 2023, p. 27). By targeting students with different learning needs, game-based learning in STEM can be a useful educational tool in attracting young learners to these fields.

Classrooms are made up of different socioeconomic backgrounds, genders, ages, beliefs, and family histories, among other characteristics. It has been noted that some of these students are more prone to face academic difficulties than others. Moreover, previous studies regarding the effects of game-based learning are needed to determine if they can contribute to promoting learning outcomes related to STEM in such student populations (Arztmann, Hornstra, Jeuring & Kester, 2023).

To some, game-based learning is a synonym for digital games in the classroom. However, when targeting specific demographics of young learners in institutional care settings, connectivity to the internet and availability of electronic devices can be limited. As some studies have noted, "students are capable and well-versed in digital games but [some schools] do not have the proper funding nor infrastructure to obtain such equipment, teacher training, or licenses to implement them in their classrooms" (Olivas, Velázquez & Duarte, 2023, p. 353).

1.2 Literary Review

In the last five years (2018 - 2023), there have been several studies regarding games-based learning in STEM. In particular, we searched the Scopus database to identify final publication research papers; we used the following keywords: games-based learning, and STEM. In our search, we came across 54 open-access research articles in English. Most studies were from the United States of America (16), Malaysia (8), Spain (6), and the United Kingdom (4). Meanwhile, 39 studies were from Social Sciences, 25 were from Computer Science, 14 were from Engineering, 11 were from Psychology, and the rest were from various regions.

Some of the main themes in previous studies on game-based learning in STEM were related to overall practices with digital game-based learning to teach specific courses or topics. Another pattern we identified in these studies was the use of game-based learning to teach topics in mathematics. Such studies noted how such an educational approach can aid in presenting mathematics in a more attractive light, whether it is by implementing a QR-based card game, a serious game, or another activity (Yung, Junaini, Kamal & Ibharim, 2020; Gil-Doménech & Berbegal-Mirab, 2019; Nurnberger-Haag, Wernet & Benjamin, 2023; Juric, Bakaric & Matetic, 2021; Ameerbakhsh, Maharaj, Hussain & McAdams, 2019; Zainal, Din, Majid, Nasrudin & Rahman, 2018).

However, taking into consideration that most institutional care settings do not have sufficient digital connectivity, nor the proper digital infrastructure, we focused our attention on studies that used non-digital-game based learning to complement the learning process of STEM education among students (Assapun & Thummaphan, 2023; Gui et al., 2023; Farihah, Norawi & Jahan, 2021; González-Tablas et al., 2020).

Some studies showed how implementing game-based learning helped students enhance their problem-solving skills in STEM education (Assapun & Thummaphan, 2023). Meanwhile, Farihah, Norawi & Jahan (2021) noted how it can aid in the learning outcome in science and mathematics (González-Tablas et al., 2020). As expected, most studies focused on educational settings and not in institutional care settings or after-school programs. However, a need to supplement or enhance learning and promote education in general often occurs in such settings outside of educational institutions.

Other studies touched on digital game-based learning, especially in the form of educational apps and their ability to aid educators in evaluating learning outcomes in young learners (Papadakis, 2021); some even included the use of game-based learning hands-on activities and software but in preschool education participants (Kalogiannakis et al., 2018). As mentioned, most of the game-based learning research we found was centered around educational institutions and digital platforms.

1.3 Objectives, Research Questions, and Hypothesis

The paper highlights the observational experiences of some of the authors, and their exploration into possibly answering the following research questions: 1) Is game-based learning in science, technology, engineering, and mathematics (STEM) education a proper approach to motivate learning? and 2) can game-based learning motivate young students from institutional care settings?

We suppose that game-based learning can be seen as a complement to after-school programs for young learners in institutional care settings. Also, we presume that STEM education can benefit from it when engaging with young learners from different sociodemographic backgrounds. There is an open debate about whether these specific groups of students do not show more improvement in evaluations after game-based activities. Nonetheless, we suppose that by offering STEM education with this component, they can become involved in one of these fields.

1.4 Justification

As noted by Olivas, Velázquez & Duarte (2023) “some factors that affect students' performance [in STEM sciences] are the lack of interest in learning, the reduced number of hours that STEM programs offer, and the lack of resources available (...) to promote (...) learning activities” (p. 352).

Additionally, the authors mentioned that “in the case of [several countries, as well as in Mexico], to implement education games, educators must think outside of the box and use the resources they have available to them (whether they are physical material, creativity, or funding)” (Olivas, Velázquez & Duarte, 2023, p. 253). By promoting active learning activities such as game-based learning, more students can become motivated to engage in STEM education (Crow and Henning, 2020).

2. Theoretical Background

Observational research has been used to understand and comprehend students' dynamics with material, subjects, activities, and pedagogies, among other categories (Anwar & Menekse, 2021). In this study, we understand observational research as one that “examine[s] affect phenomena in group interactions” (Jones, Volet, Pino-Pasternak, 2021, p. 349). We also considered how such research can leave out important data from the final analysis or perception of the authors (Lee et al., 2021).

Comprehending that observational research may present bias or surface-level interpretation of processes, we were interested in capturing the approach of the teachers and instructors in such game-based learning activities. As Sundberg, Kirk & Lindahl noted (2021), "observations show what teachers actually do in their lessons. Accordingly, classroom observation seems a suitable method to assess teachers' approaches to foster [self-regulated learning]" (p. 500). Game-based learning can aid in introducing STEM to students from different sociodemographic backgrounds (Stohlmann, 2023, p. 27).

3. Materials and Methods

To carry out our observational research, we looked for activities that focused on STEM education, specifically biomedical engineering. The game-based learning activities were implemented in two institutional care settings in Northwestern Mexico, in the State of Sonora in December 2023. At the time, both institutions had young boys and teenagers (male) between the ages of 6 years old up to 17 residing on their premises. In this activity, 32 male participants interacted with game-based activities (22 from one institution, and 10 from the other).

We asked permission from the institutions to conduct the events; written and oral information regarding the event and its activities was provided. Participation was voluntary, and the identities of the people present were kept anonymous. Additionally, our focus of the study was on our (authors) experience as volunteers in a game-based learning activity.

The games were set in stages and would rotate participants every time one of the activities concluded: Jeopardy, *Abremente*, Hedbanz, *Lotería*, and others. The activities were planned by high school students of a STEM group, *Juventud Biomédica* (Spanish for Biomedical Youth), with the guidance of one of the authors. We introduced the games during winter break due to the accessibility of the members and the willingness of both institutions. We held the events on a weekend, one day per institution, from 11:00 a.m. to 3:00 p.m. The games and their presentations were the same for both institutions. They were arranged the following way: in a station rotation model, the students could win a small prize (small foam play balls with a series of attractive designs, ranging from sports themes to planets and colorful ones).

In the first stage, we used the board game named "*Abremente*" (See Image 1). The original game provides cards with questions about a variety of topics according to the age of the players. For observational research purposes, the cards were STEM-related. The game included a board that had a path of squares to follow, a dice, and five tokens. Two members of *Juventud Biomédica* led the activity and assigned an order to the players' group. The members proceeded to read the questions out loud for all participants to hear them (the questions were selected depending on the participants' age). Each player could advance one square for every correct answer they had. The winner was the one that ended nearest the finish line after each stage ended.

Figure 1: "*Abremente*" board game (STEM-related) photographs.

For the second game, we adapted the board game Hedbanz to STEM-related content (see Image 2). Two members from the STEM group designed all of the cards, replacing the original objects with elements such as a 3D printer, a cell, a pill with an integrated camera, DNA, and a heart, among other STEM-related content. Additionally, we provided a card with base questions including "Can I detect diseases?", "Am I a human body part?", "Do I serve as ___ ?" among others.

Figure 2: "*Hedbanz*" game (STEM-related) photographs.

Each participant had a timeframe of 90 seconds to guess the element in their card by asking key questions. The STEM group member in charge of this stage answered the questions and gave the students a play coin for every element guessed. The winner was the one who accumulated more coins. We understand that a system of rewards can be somewhat controversial to some; however, we perceive that encouragement and prize recognition among such young learners (in orphanages) can be a motivation.

In the third stage, we followed the same process but with the Mexican game of "*Lotería*". The game included 32 different element cards and 5 player cards. Each player card contained a random and unique selection of 16 STEM-related elements. These STEM group members designed the cards and led the activity. To play, the members randomly selected one element card at a time and read it out loud. Following the same instructions as the Mexican game, if the participants had the element announced in their player cards they needed to mark the image with a token. The winner was the first person that completed a full card with sixteen tokens and shouted out "Lotería".

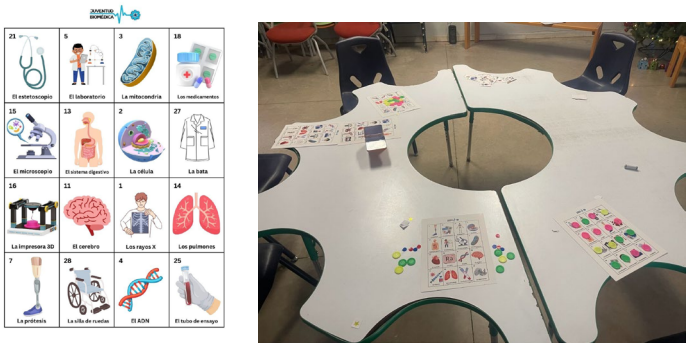

Figure 3: "*Lotería*" game (STEM-related) photographs.

Furthermore, we designed a fourth game. Even though it was rather simple, it gained recognition among the players. The game consisted of a Jeopardy-like dynamic, where STEM-themed questions were asked to the participants, and whoever pressed the button at the center of the table first earned the right to choose one of the multiple-choice answers. The questions that were included had the purpose of teaching about the functions and elements that encompass biomedical engineering, as well as its relationship with other STEM disciplines. One of the observations that we would like to emphasize was the natural competitiveness and eagerness to learn that was shown by the participants when trying to gain points and win.

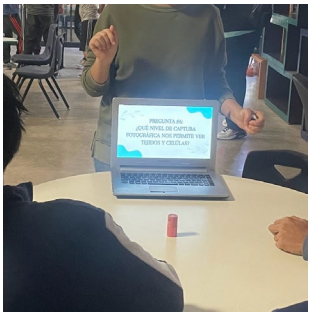

Figure 4: "*Jeopardy*" game (STEM-related) photographs.

For the final stage, we aimed for an immersive engineering practice and presented them with the robotic hand project. Each hand was created using recycled cardboard, straws, linen thread, hot silicon glue, scissors, a pencil, and a ruler. To avoid risking student safety and adhere to our tight schedule, we preassembled a base hand with cardboard and straws. During the event, the leading member of the stage paired the participants and provided them with one base hand, linen thread, and a ruler. The couples worked together, using the materials and their creativity to make their hand functional. After that, the challenge was to create a pyramid with three plastic cups by only using the robotic hand. The winning team was the one that finished the pyramid first.

Figure 5: "*Robotic hand*" project (STEM-related) photographs.

To execute the station rotation model, participants were divided into groups of four and five members in the appointed stages. The games of scientific Jeopardy and *Lotería* were planned to last fifteen minutes, while the robotic hand and scientific Hedbanz lasted thirty minutes. At the end of the designated time, all the participants were free to play in the stations they were more interested in. This model was adopted to maximize their interaction and experience with all of the games prepared.

Game-based learning was used to incentivize the student group to learn about STEM in an engaging manner. Furthermore, we thought of adapting the content to already existing board games as most of the participants in the age range were already familiarized with them and their rules and dynamics. Our priority consisted in transforming them into STEM-related content. "*Abremente*" was meant to give general science and math information through the questions asked based on age. Scientific Hedbanz aimed to awaken participants' curiosity by making them formulate questions to guess STEM elements. Likewise, the scientific theme "*Lotería*" intended to enable students to identify elements and to relate them to their correct labels. Meanwhile, Jeopardy sought to test their current knowledge in a manner that endorsed eagerness to learn through the dynamic of questioning, answering, and enhancing their critical thinking skills. Finally, the robotic hand project aimed to apply their knowledge about biological movements and their creativity to create a functional device.

4. Results and Discussion

This paper intends to present the experiences of the authors as volunteers in two institutional care settings, implementing game-based learning activities. We must note that other studies present mixed findings, where using game-based learning among different sociodemographic populations of students did not show significant improvement in evaluations. Nonetheless, it is fundamental to study further such methodologies to teach STEM and their long-term impact on young participants.

4.1 Game-based Learning in Science, Technology, Engineering, and Mathematics (STEM) Education as a Motivator in Learning

This observational research integrated game-based learning in science education. We witnessed these activities' impact on participants from both institutional care settings. STEM content was accurately adapted to games, allowing participants to acquire knowledge in engaging ways. After playing and understanding the event dynamic, they willingly participated.

We observed a higher motivation, particularly in knowledge-based competitions, such as scientific Jeopardy and Hedbanz. In the robotic hand project, we were impressed with how participants went beyond the game´s objective and thought of new challenges (they brought classroom materials for assembling higher towers with the hand in the least possible time).

In this activity, we noted how the robotic hand could be a hands-on approach activity that may potentially develop or enrich their curiosity, and motivation in learning about STEM fields (Kalogiannakis et al., 2018). We believe that such results could be potentially enhanced if we complement the activity with another one that has a digital element to it. Also, we noticed how the participants kept playing after the designated time ended. Game-based learning introduced students to a new way of interacting with STEM-related content, awakening their curiosity and interest as they mentioned to us.

4.2 Learning Motivation in Vulnerable Student Groups

In 2014, the OECD noted that Mexico's annual expenditure on spending per student was already well below the OECD average. Nonetheless, in 2017 the budget directed to public education was cut by 11%, and the funding aimed for teacher training programs was radically reduced by 40%. Taking into account the aforementioned challenges, we approached the task of offering children in institutional care settings in the city of Hermosillo, Sonora, the opportunity to learn simple yet rich educational content that they do not usually review in class.

Throughout the execution of the distinct activities, we perceived the students' eagerness to learn new, STEM-related content. Even after the station rotation concluded, they wanted to extend the timeframe set for each activity and continue playing. It was visible and rather endearing that they expressed their gratitude for being able to be involved in the activities, gaining a new sense of motivation and aspirations. As noted by Stohlmann (2023), game-based learning can enrich or develop a motivation to learn among young learners about the different STEM fields. There have been studies performed with such populations of participants and the response was positive, just as it was in the case of our research.

5. Conclusions

This study sought to forge the application of game-based learning in STEM by organizing events for orphans at two institutional care settings in Northwestern Mexico. We observed that an environment of curiosity was achieved with the help and support of the youth group, *Juventud Biomédica.* In essence, we believe we made a positive impact on them.

We understand that one of the limitations of our observational research was the reduced sample size of participants. We are aware of potential variations in the findings of broader studies. Additionally, technological limitations in both institutions made us avoid using technology in the games. Despite this, we found that game-based learning was considered a novelty, innovative, and motivational way of engaging young populations to learn and become curious about the STEM field. We interpreted their willingness and enthusiasm as an affirmation of an enriching experience with game-based learning for science education.

To further the practice of game-based learning in STEM education, it is essential to continue to broaden studies to more institutions. We are eager to see how this can be applied to different contexts or locations (schools, recreation centers, workshops, etc.) and analyze its impact. It would also be beneficial to create and apply measurable tools with the capacity to evaluate this outcome. Contributing to the improvement of game-based learning and participation in STEM, we are encouraged to expand this study and develop innovative ways of learning.

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Declaration of generative AI and AI-assisted technologies in the writing process:

During the preparation of this work, the author(s) used the free version of Grammarly to check the correct grammar of our original text, since our native language is not English but Spanish. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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