OmniaScience

Journal of Technology and Science Education

JOTSE, 2024 – 14(1): xx-yy – Online ISSN: 2013-6374 – Print ISSN: 2014-5349

https://doi.org/10.3926/jotse.2219

DEVELOPING LEARNING SKILLS THROUGH GAME-BASED LEARNING IN COMPLEX SCENARIOS: A CASE IN UNDERGRADUATE LOGISTICS EDUCATION

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Received April 2023

Accepted July 2023

Abstract

This study investigates the impact of game-based learning (GBL), an increasingly popular educational approach, on the development of self-directed learning (SDL) skills in complex scenarios, particularly in undergraduate logistics education. A key component of the three year study is LOST (Logistics Education Simulator), a serious game platform, deployed in an undergraduate engineering course in Mexico. An extensive literature review was carried out using Scopus to examine recent works published between 2019 and 2024, providing a state-of-the-art overview of the field. Subsequently, a survey based on the scale created by Fisher, King and Tague (2001), known for its extensively evaluated internal consistency, revealed five distinct factors of self-directed learning. The findings underscore that the LOST platform significantly enhances self-directed learning, promoting the development of Self-management Skills, Openness to Learning Opportunities, Initiative and Independence in Learning, Self-concept as an Effective Learner, and Love of Learning. The students demonstrated a significant increase in their perception of these skills over the course of the study, highlighting the effectiveness of GBL in promoting such learning skills. These findings highlight the multidimensional nature of learning skills that can be fostered through GBL. The study concludes by discussing the vital role of GBL in complex scenarios, particularly in enhancing the development of self-directed learning skills in undergraduate logistics education.

Keywords – Serious games, Game-based learning, Self-directed learning, Logistics education, Educational innovation, Higher education, Virtual learning.

To cite this article:

Pacheco-Velazquez, E., Rodés, V., & Salinas-Navarro, D. (2024). Developing learning skills through game-based learning in complex scenarios: A case in undergraduate logistics education. *Journal of Technology and Science Education,* 14(1), xx-yy. https://doi.org/10.3926/jotse.2219

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1. Introduction

In the 21st century, game-based learning (GBL) has become increasingly popular as an educational approach. This technique effectively motivates individuals to voluntarily invest numerous hours in skill development and knowledge acquisition (Bond, Buntins, Bedenlier, Zawacki-Richter & Kerres, 2020).

Extensive research emphasizes the various benefits associated with this approach. Games foster continuous learning, enhance comprehension, improve retention, increase participation and engagement, facilitate student collaboration, and promote understanding, among other advantages (Boskic & Hu, 2015). To further explore this direction, this article presents a quantitative study on complex learning skills development in a game-based experience in a logistics undergraduate course within the field of engineering education in México. The course incorporates a serious game and a gamified platform to support self-directed learning (SDL). The aim of this course design was to enhance students' learning experiences in logistics and cultivate their SDL skills within complex scenarios. In 2017, the online plattform "GOAL Project" was created to support undergraduate students' learning on supply chain management and increase their engagement. This platform contains innovative learning materials, including videos, notes, quizzes, simulators, and games (Pacheco-Velázquez, 2015; Pacheco-Velazquez & Aguilar-Avalo, 2019; Pacheco-Velazquez & Viscarra-Campos, 2019; Salinas-Navarro, Pacheco-Velazquez, Arana-Solares & Palma-Mendoza, 2020; Pacheco & Palma-Mendoza, 2021; Pacheco-Velazquez, 2022). An adapted version of a well-known SDL survey (Fisher et al., 2001) was implemented from 2017 to 2020 across multiple academic terms. The results demonstrate that through the utilization of the Logistics Simulator (LOST), students were able to develop both independent learning abilities and problem-solving skills, as well as cultivate logical thinking in the context of complex logistics scenarios.

The Fourth Industrial Revolution has brought about a transformative era, integrating digital and information technologies into company processes. This unpredictable society requires economic entities to adapt swiftly and accurately to evolving contexts (Minciu, Berar, & Dobrea, 2020). This paradigm shift impacts management and employment, as new business models emerge, demanding novel learning skills. Professionals must become adept at navigating complex situations, making effective responses crucial. Individuals must become "learners of learning", and universities must prepare to confront these challenges (LeBlanc, 2018). Therefore, universities must prioritize the incorporation of competencies that foster greater autonomy and independent learning capacity, enabling students to navigate changing situations, uncertainty, and ambiguity (Ramirez-Montoya, Castillo-Martínez, Sanabria-Zepeda & Miranda, 2022; Alfaro-Ponce, Patiño, & Sanabria, 2023). These requirements encompass a broad range of competencies, including openness to new ideas, critical thinking, problem-solving, information search and selection, initiative, and self-direction (van Laar, van Deursen, van Dijk & de Haan, 2020; Almeida & Simoes, 2019). Therefore, this study acknowledges the necessity of promoting self-directed learning (SDL) and implementing strategies to develop the essential skills required for the effective integration of graduates into the labor market (Tekkol & Demirel, 2018). In the short term, universities will need to undergo significant changes, such as the establishment of personalized education tailored to individual needs and the adoption of alternative approaches based on emerging digital communication technologies.

Researchers are increasingly developing educational games to support the teaching of essential 21st-century skills (Qian & Clark, 2016). These skills, categorized as learning to know, do, be, and live together, include elements of self-directed learning (SDL) like problem-solving, critical thinking, autonomy, and responsibility (Scott, 2015). Moreover, they are closely connected to developing a systemic vision, problem-solving abilities, self-management, information technology proficiency, and decision-making skills (Sun & Song, 2018; Hubl & Fischer, 2017; Lindberg, 2019; Wong & Mok, 2019; Toh & Kirschner, 2020). Serious games, in particular, are effective in fostering these skills due to their flexibility, enabling students to learn at their own pace (Toh & Kirschner, 2020). Games engage players, offer clear observation opportunities, and encourage the exploration of multiple strategies, contributing significantly to skill elevation (Hallros & Palsson, 2021). As Higher Education adapts to the future, substantial changes are necessary, including transforming teaching methods, conceptualizing new evaluation systems, and integrating innovative technologies to enhance learning in complex scenarios. Critical skills required in the logistics industry have been identified, encompassing social, decision-making, problem-solving, time management, and general knowledge skills (Lutz & Birou, 2013). In logistics undergraduate courses, the increasing use of gamification techniques suggests enhanced engagement and

performance (Hubl & Fischer, 2017). Furthermore, simulation frameworks have been employed for supply chain modeling and optimizing production planning problems.

When students engage in GBL, they can test their knowledge and enhance understanding of previously learned concepts (Crocco, Offenholley & Hernandez, 2016). Games offer repeated exercises, adjustable difficulty levels, and modified challenges, providing better support than traditional instruction. GBL fosters perseverance and independence in the learning process (Almeida & Simoes, 2019; Chris, Moldovan, Murphy, Pathak & Muntean, 2018). Video games can offer meaningful contexts and visual representations, making learning material more accessible and relevant, especially for students who may not thrive in traditional environments (Payne, Keith, Schuetzler & Giboney, 2017). Serious games, a part of GBL, serve an educational purpose beyond entertainment, offering specific contextual situations for learning (Abt, 1987; Laamarti, Eid & El-Saddik, 2014). Knowledge acquisition in serious games is tied to the game's progression and students' experiential and instrumental attitudes (Rosenthal & Ratan, 2022). They provide valuable learning alternatives, fostering cognitive skills like attention, perception, creativity, and abstract thinking (Zhonggen, 2019; Gaurav, Kaushik, Supraja, Yadav, Gupta & Chaturvedi, 2022). Serious games effectively foster and strengthen essential learning skills, including mathematical and logical reasoning abilities among high school students (Sánchez & Lara, 2021). However, few studies explore the relationship between complex thinking skills and serious games, especially when players can engage at their own pace without assigned learning objectives (Rosenthal & Ratan, 2022).

SDL enhances students' learning flexibility and independence by developing competencies to navigate uncertainty, search for information, create effective learning strategies, and establish connections between variables (Tekkol & Demirel, 2018). These sub-competencies also foster valuable skills for addressing complexity in a knowledge-driven society (Cavicchi, 2021). SDL is compatible with new technologies, enabling the development of online educational platforms with videos, games, simulators, augmented reality, and virtual reality, offering flexibility and independence to students, and a strong predictor of readiness for online learning (Luu, 2022; Herrera & Valenzuela, 2019; Prihastiwi, Prastuti & Eva, 2021). In SDL, students take responsibility for diagnosing their learning needs, setting goals, selecting materials and strategies, and evaluating outcomes (Knowles, 1975). Self-direction includes self-management, self-control, and self-motivation (Garrison, 1997), crucial attributes for online learners who must organize their own learning. Students with SDL skills perform better in online settings (Chou, 2012). As Higher Education adopts student-centered approaches, SDL gains importance. Digital-native students readily absorb multimedia information, making video games valuable tools for developing SDL in engaging environments that foster independent learning (Kivunja, 2014).

2. State-of-the-Art

The state-of-the-art review aimed to explore the intersection between GBL and the development of learning skills in complex scenarios. To conduct this analysis, a literature review was carried out using Scopus, utilizing the query: TITLE-ABS-KEY (learning AND skills AND game-based AND learning AND complexity) AND PUBYEAR > 2018 AND PUBYEAR < 2024.

The search yielded 34 journal articles and proceedings, which were subjected to a thorough analysis. The examination primarily focused on the Title and Abstract sections, with some cases involving a full-text review. One false positive was identified during this process. The analysis was performed to identify emergent categories based on the primary focus of each paper. Table 1 below presents the papers classified into the emergent categories identified during the analysis.

The retrieved references encompass a broad spectrum of 154 topics, offering a diverse range of subjects within the domain of game-based learning. These topics span various forms of learning, such as "E-learning", "Active Learning", and "Self-directed Learning". Additionally, specific aspects of games and gaming are explored, including "Serious Games", "Game Design", and "Simulation". Educational environments and institutions, such as "Higher Education", "Educational Institutions", and "Virtual Classroom", are also covered in the dataset.

Category	Reference
Game-Based Learning Methods	Haendler 2019; Rumeser & Emsley, 2019; Dyulicheva & Glazieva, 2022; Bastos, Silva, Poza-Lujan & KaiSchleut, 2020; Neves & Sousa, 2019; Pacheco, Palma, Salinas & Arana, 2020; Bühler, Jelinek & Nübel, 2022; Horvat, Jagust, Veseli, Malnar & Cizmar, 2022; Santana, 2023; Cruz-Martinez, Soto & Benito, 2022; Taylor, 2020; Tavares, 2022; Sevcenko, Ninaus, Wortha, Moeller & Gerjets, 2021; Sincharoenkul, Tongtep & Boonlamp, 2020; Buzady, Wimmer, Csesznak & Szentesi, 2022; Mahmoud, Kidmose, Broholm, Pilawka, Illés, Magnussen et al., 2020; Bastos et al., 2020; Tseng, Doll & Varma, 2019; Hansen & Elbæk, 2019; Camacho, Sahu & Esteva, 2019; Sharma, Bhagat, Huang & Chen, 2022; Prompolmaueng, Wetmaha & Jamsri, 2021; Lezama, Manotas & Mercado-Caruzo, 2020.
Learning Skills Development	Pogge & Davis, 2021; Pacheco et al., 2020; Alfaro-Ponce et al., 2023; Cruz-Martinez et al., 2022 Tavares, 2022; Sincharoenkul et al., 2020; Cecchi, Rodríguez & Dahl, 2023; Sharma et al., 2022; Prompolmaueng et al., 2021.
Complexity	Czauderna, Guardiola, Lux & Budke, 2021; Rumeser & Emsley, 2019; Sincharoenkul et al., 2020; Biswas, Rajendran, Mohammed, Goldberg, Sottilare, Brawner et al., 2020; Zhang, Gao, Chen, Liu, Wang & Liao, 2020; Hainey, Baxter & Ford, 2020.

Table 1. State-of-the-art categories and references

Top 5 Topics	Bottom 5 Topics (among others)
Game-based Learning (20)	Complex Decision Making (1)
Students (11)	Collaborative Learning (1)
Serious Games (11)	Cognitive Strategy (1)
Gamification (8)	21 Century Skills (1)
Computational Thinking (7)	Complex Problems (1)

Table 2. Most and less cited topics within the references

Furthermore, the set of references delves into technological aspects related to game-based learning, featuring topics like "Augmented Reality", "Smartphone Applications", and "Artificial Intelligence". Skills and competencies are addressed as well, with topics including "Thinking Skills", "Technical Skills", and "21st Century Skills" forming part of the dataset. Moreover, specific student populations are represented, with references focusing on "Students", "Adults", and "Autistic Children". The wealth of topics covered in the dataset makes it a comprehensive resource for exploring the diverse landscape of GBL.

This array of topics illustrates the multifaceted nature of game-based learning research to date, encompassing diverse methods, technologies, and educational contexts. The variety of subjects also indicates the potential for GBL to address a range of learning needs and educational goals. Following in Table 2 most and less cited topics are presented.

The set of references showcases a diverse range of subject areas, with a notable concentration in Computer Science, accounting for 25 references. This highlights the significant role of game-based learning research within the computer science domain, where innovative technologies and digital advancements greatly influence educational methodologies.

Following closely, Social Sciences are represented with 23 references, emphasizing the relevance of game-based learning in understanding human behavior, cognition, and the social impact of educational interventions. This indicates the importance of exploring how games can effectively support learning outcomes and engagement.

Additionally, 14 references come from the field of Engineering, underscoring the application of game-based learning in engineering education. Interactive simulations and serious games are leveraged to enhance technical skills and foster problem-solving abilities among engineering students.

Overall, this diverse collection of references demonstrates the multidisciplinary nature of game-based learning and its influence in various fields, reaffirming its potential to revolutionize and optimize modern educational approaches.

Additionally, the dataset includes 2 references from Decision Sciences, reflecting the growing interest in using game-based approaches to improve decision-making skills and strategies across various industries. Nursing and Psychology each contribute 2 references, underscoring the value of game-based learning in the healthcare sector to enhance clinical reasoning, decision-making, and other critical competencies among healthcare professionals.

This remarkable variety of subject areas showcases the truly interdisciplinary nature of game-based learning research, with its applications extending across multiple domains. It highlights the versatility of game-based learning as an effective educational tool that can be customized to suit different academic fields and learning objectives, making it a valuable asset for educators and researchers alike.

In Figure 1, a graphic representation illustrating the percentage distribution of different domains in the retrieved references is presented, providing a visual overview of the diverse range of subjects covered in the dataset.

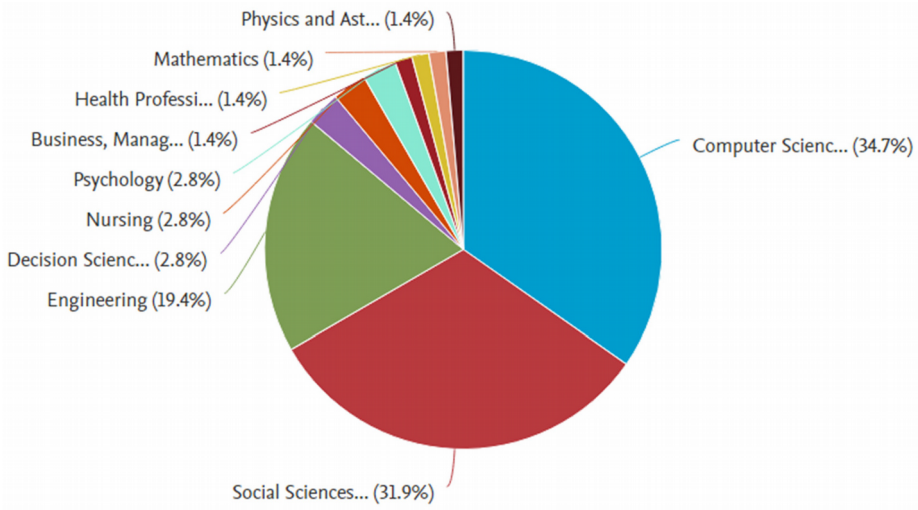

Figure 1.Different domains in the retrieved references (%) (Copyright © 2023 Elsevier B.V. All rights reserved. Scopus® is a registered trademark of Elsevier B.V.)

The top 20 most common words reveal key insights. "Game" and "learning" are central topics, with a focus on students' "skills" development. "Based" and "games" suggest a significant interest in game-based learning approaches. "Education" and "design" indicate efforts to create engaging learning experiences. Researchers explore the "complexity" of implementing games in education, with a focus on "educational" contexts. "Knowledge" and "results" are crucial in understanding the impact of game-based learning. "Teaching", "new", and "using" show innovative efforts in utilizing games for instruction. The frequent use of "study" and "research" highlights the substantial body of research in this field. Overall, the analysis indicates a thriving field, with researchers committed to leveraging games to enhance learning, foster essential skills, and address modern educational challenges.

Indeed, the state-of-the-art review presents valuable insights into the current landscape of game-based learning research and its potential to enhance learning skills in complex scenarios. The comprehensive exploration of diverse topics and subject areas demonstrates the wide-ranging scope of this field, prompting further investigation into the application of game-based learning for developing crucial skills in educational settings.

The subsequent sections of the study, namely the methodology, results, and discussion, delve into the findings and experiences of a quantitative four-year study conducted with Mexican engineering undergraduate students. This study offers a valuable contribution to the existing research, shedding light on the effectiveness and impact of game-based learning specifically within the context of engineering education. By sharing their experiences and data, the study provides concrete evidence and practical insights that can inform future educational practices and strategies.

3. Methodology

3.1. Design and Instruments

Based on the classical literature on self-directed learning, the scale created by Fisher et al. (2001) was utilized, whose internal consistency has been extensively evaluated and cited in more than 370 research works. Through factor analysis, the survey revealed five distinct factors, each capturing different aspects of self-directed learning. These factors have been named as follow:

- Factor 1: Self-management Skills.
- Factor 2: Openness to Learning Opportunities.
- Factor 3: Initiative and Independence in Learning.
- Factor 4: Self-concept as an Effective Learner.
- Factor 5: Love of Learning.

The study utilized a 52-question survey to assess whether there was a change in student perception regarding the importance of self-directed learning before and after the implementation of LOST (the platform and game used for the study). Additionally, the research aimed to explore any potential associations between the survey results and the methodology employed in the classroom.

The first phase of the study involved 311 Mexican engineering undergraduate students who used the platform and game during the school periods of August-December 2017, January-May 2018, August-December 2018, and January-May 2019. The survey was administered to these students before and after their engagement with the LOST platform, enabling researchers to analyze any shifts in their perception of self-directed learning's significance and its link to the utilized methodology.

In the second phase, the experiment was conducted during the semesters of August-December 2019 and January-May 2020, specifically in a logistics curricular undergraduate course. The study focused on a population of 53 fifth-semester students pursuing Industrial Engineering. Similarly, the survey was administered to these students at the beginning and conclusion of the course to evaluate potential significant differences in their perception of self-directed learning competencies development.

5.2. Results

Factor analysis serves as a powerful tool to reveal underlying patterns and structures within the data, providing meaningful insights into the dimensions of self-directed learning in this study. The results of the survey application revealed that the 52 questions of the questionnaire could be grouped into five distinct factors. These factors were determined through a principal component analysis extraction method using a Varimax rotation with a Kaiser normalization. The analysis indicated that all items were significant ($p < 0.05$), confirming the validity of the factor structure. The exploratory factor analysis yielded the following five factors, which collectively explained 63.12% of the total variance:

Factor 1: Self-management Skills: This factor encompasses qualities related to an individual's ability to organize, manage time effectively, demonstrate self-discipline, and take responsibility for their actions.

Factor 2: Openness to Learning Opportunities: This factor reflects an individual's willingness to embrace and explore various learning opportunities, demonstrating a receptive and open mindset towards acquiring new knowledge.

Factor 3: Initiative and Independence in Learning: This factor pertains to an individual's proactiveness and self-reliance in driving their learning journey, taking initiative to engage in learning activities independently.

Factor 4: Self-concept as an Effective Learner: This factor focuses on an individual's perception of themselves as capable and effective learners, reflecting their self-confidence in their learning abilities.

Factor 5: Love of Learning: This factor represents an individual's intrinsic motivation and passion for learning, demonstrating a genuine enthusiasm and enjoyment for the process of acquiring new knowledge and skills.

By categorizing the questions into these five factors, the survey effectively reduces the complexity of the data, allowing researchers to analyze and interpret students' self-directed learning skills based on these distinct categories.

In the second application moment of the study, the researchers sought to determine whether significant differences existed in the students' perception of developing self-directed learning competencies. To assess these differences, a paired t-test was conducted to compare the responses between the first and second surveys administered to the students.

The results of the paired t-test are presented in Table 4. Based on these results, it can be concluded with 95% confidence that factors considered in students' self-directed learning demonstrated a statistically significant increase. This indicates that there was a noticeable improvement in the students' perception of developing self-directed learning skills over the course of the study.

The results of the paired t-test provide strong evidence to support the positive impact of the LOST intervention on students' perception of developing self-directed learning competencies. This finding reinforces the effectiveness of the game-based approach in fostering important skills for self-directed and independent learning among the participants.

Question	1	2	3	4	5
I am organized	0.718				
I manage my time well	0.704				
I am self-disciplined	0.650				
I am responsible	0.631				
I prioritize my work	0.618				
I set specific times for my study	0.606				
I set strict time frames	0.548				
I solve problems using a plan	0.496				
I am systematic in my learning	0.465				
I am methodical	0.450				
I need minimal help finding information	0.384				
I have good management skills	0.359				
I enjoy studying	0.356				
I can focus on a problem	0.305				
I am willing to accept advice from others		0.770			
I am open to new ideas		0.705			
I am open to new learning opportunities		0.668			
I will ask for help in my learning when necessary		0.647			
When presented with a problem I cannot resolve, I will ask for assistance		0.599			
I am responsible for my own decisions/actions		0.572			
I like to gather the facts before I make a decision		0.480			
I am willing to change my ideas		0.473			

Question	1	2	3	4	5
I learn from my mistakes		0.406			
I critically evaluate new ideas		0.378			
I believe the role of the teacher is to act as a resource person		0.371			
I prefer to direct my own learning			0.693		
I prefer to set my own learning goals			0.645		
I prefer to plan my own learning			0.635		
I prefer to set my own criteria on which to evaluate my performance			0.612		
I evaluate my own performance			0.600		
I can be trusted to pursue my own learning			0.598		
I prefer to set my own learning goals			0.555		
I need to be in control of what I learn			0.469		
I like to make decisions for myself			0.437		
I need to know why			0.369		
I like to evaluate what I do			0.323		
I have high belief in my abilities				0.651	
I am in control of my life				0.496	
I am aware of my own limitations				0.466	
I am assertive				0.408	
I am confident in my ability to search out information				0.395	
I am logical				0.364	
I like to solve (answer) puzzles/questions				0.328	
I can find out information for myself				0.307	
I want to learn new information					0.652
I need to learn					0.472
I enjoy learning new information					0.462
I enjoy a challenge					0.361

Table 3. Rotate Component Matrix

Factors	First Survey	Second Survey	Difference of Means	t-stat	p-value
Self-management Skills	28.763	29.731	0.968	2.532	0.006**
Openness to Learning Opportunities.	72.165	73.116	0.951	2.174	0.016*
Initiative and Independence in Learning.	30.923	32.33	1.407	2.391	0.009**
Self-concept as an Effective Learner.	25.438	26.372	0.934	1.956	0.030*
Love of Learning	31.342	33.069	1.727	2.394	0.007**

* Significant at 5%; ** Significant at 1%

Table 4. Means of each survey and Comparison of Means

6. Discussion and Conclusions

The findings from this study provide valuable insights into the role of game-based learning in complex scenarios, particularly within the context of developing self-directed learning skills. The emergence of five distinct factors from the survey - Self-management Skills, Openness to Learning Opportunities, Initiative and Independence in Learning, Self-concept as an Effective Learner, Love of Learning - aligns with the multidimensional nature of learning skills that can be fostered through game-based learning, as noted by Bühler et al. (2022), Dyulicheva and Glazieva (2022), Horvat et al. (2022), and Sharma et al. (2022).

Our study revealed a significant increase in factors considered in students' self-directed learning. This supports the existing literature on the potential of game-based learning to enhance self-directed learning skills (Taylor, 2020; Alfaro-Ponce et al., 2023; Pacheco et al., 2020; Bastos et al., 2020; Tavares, 2022). These results also align with the observations of Sharma et al. (2022) and Camacho et al. (2019), who

found a positive impact of game-based learning on computational thinking, a key component of self-directed learning.

The development of self-management skills and the students' openness to learning opportunities, as revealed in our study, resonate with the findings of Santana (2023), Horvat et al. (2022), and Lezama et al. (2020). These studies emphasized the role of game-based learning in fostering problem-solving and lifelong learning skills, essential components of self-directed learning.

The importance of initiative and independence in learning found in our study aligns with the findings of Alfaro-Ponce et al. (2023), Tavares (2022), and Sharma et al. (2022). These studies discussed the impact of game-based learning on academic skills development and the importance of encouraging independent learning.

The self-concept as an effective learner and love of learning, which were among the factors emerging from our survey, are consistent with the research conducted by Pacheco et al. (2020), Lezama et al. (2020), Bühler et al. (2022), and Dyulicheva & Glazieva (2022). These studies highlighted the importance of creating an engaging and immersive learning environment through game-based learning, thereby fostering a positive self-concept and a love for learning.

However, while our study and the existing literature underscore the effectiveness of game-based learning, several potential avenues for future research have been suggested. These include the integration of advanced technologies into game-based learning (Sharma et al., 2022; Camacho et al., 2019), the need for longitudinal studies to understand the long-term effects of game-based learning (Pacheco et al., 2020; Bühler et al., 2022), and the exploration of the customization and personalization of game-based learning environments to cater to individual learner needs (Bastos et al., 2020; Taylor, 2020).

The results of the study highlight the numerous advantages of using simulators for learning, particularly in the field of logistics. Simulators offer a safe and controlled environment for practicing and developing skills in complex scenarios, providing immediate feedback and adaptability to individual students' needs. They are also cost-effective and enable hands-on training, improved decision-making, reduced risk, and increased efficiency and collaboration.

The Logistics Simulator LOST proves to be particularly valuable for undergraduate students, as it allows them to experience realistic training scenarios, identify areas for improvement, and gain a better understanding of various concepts in the logistics process. These simulations contribute significantly to the skills development of students.

Moreover, the use of the LOST simulator fosters the development of SDL skills among undergraduate students. The study recognizes the importance of SDL skills in preparing students to face the complex challenges of contemporary society and the workforce in the 21st century. The factors identified in Table 1 contribute to the cultivation of essential competencies, such as self-determination in setting goals, confidence in learning abilities, openness to new learning opportunities, and a genuine desire for continuous learning.

The study also presents significant differences in students' perception of the importance of these SDL factors, particularly at the end of the course. The emphasis on self-management of learning and interest in learning differently becomes more pronounced as students progress through the course, demonstrating the positive impact of the learning environment on SDL skill development.

However, the study acknowledges some limitations of the self-directed learning approach. Not all students may be equally capable of complete autonomy in their learning, and some may require a gradual transition towards self-directed learning. Implementing the approach might also demand more time and resources from teachers. Additionally, certain topics may require a more direct instructional approach, and assessing and validating learning outcomes in an SDL context can present challenges.

Despite these limitations, the study emphasizes the overall benefits of self-directed learning and the valuable role played by simulations in enhancing SDL skills and preparing students for the demands of an ever-changing and complex world.

Although the case has certain limitations as it is based on a sample of undergraduate logistics engineering students in Mexico, these limitations are mitigated as it is a case of application of a specific simulator designed especially for this purpose, and whose findings are generalizable to self-directed learning studies. In addition to this, the findings are promising and have implications for practice and research. Future research could aim to replicate and extend these findings in different contexts and disciplines, as suggested by Bastos et al. (2020), Lezama et al. (2020), and Sharma et al. (2022).

In conclusion, the study's findings, in conjunction with existing literature, strongly support the use of GBL to enhance SDL skills in complex scenarios. This approach proves to be valuable in various educational contexts and disciplines. However, further research is needed to fully unlock the potential of game-based learning and refine its implementation for optimal outcomes.

Currently, the development of an advanced version of the simulator is underway through the S4L (Simulating for Learning) project. This educational platform aims to validate the development of reasoning for complexity and SDL competencies in various stakeholders, including students, academics, decision-makers, and representatives from the business sector. By integrating elements of Industry 4.0, such as cloud computing, artificial intelligence, simulation, serious games, biometrics, data analytics, and open resources, the platform seeks to train professionals who are equipped to address lifelong learning needs effectively. The significance of this platform lies in its contribution to the general welfare of society. By preparing individuals to make more informed decisions efficiently, it fosters a more competitive industry and enhances the overall decision-making processes. The platform's potential users will have the opportunity to acquire knowledge and skills in a playful manner, observe the consequences of their decisions across different organizational areas, identify critical variables affecting real processes, and develop intrinsic motivation to explore and experiment with new strategies for problem-solving and optimization.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors acknowledge the financial support of Tecnológico de Monterrey through the "Challenge-Based Research Funding Program 2022". Project ID # I005 - IFE001 - C2-T3 – T

Also, academic support from Writing Lab, Institute for the Future of Education, Tecnológico de Monterrey, México.

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Journal of Technology and Science Education, 2024 (www.jotse.org)