

# R E L A T E C

Latin American Journal of Educational Technology

2024  
Vol 23 (2)

ISSN: 1695-288X



Nodo Educativo (Research Group)  
Publications Service – University of Extremadura (UEX)  
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R E L A T E C

Latin American Journal of  
Educational Technology

**2024 - Volume 23 (2)**

Biannual Journal

Start date: 2002

**<http://relatec.unex.es>**



PUBLICATIONS SERVICE  
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Received: February 23, 2024

Accepted: June 20, 2024

Author's address:

<sup>1,2</sup> Departament de Didàctiques Aplicades. Institut de Recerca en Educació (IRE). Facultat d'Educació, Universitat de Barcelona. Campus Mundet, Edifici Llevant, Passeig de la Vall d'Hebron, 171- Barcelona (Spain)

<sup>3</sup> Instituto de investigaciones médicas Hospital del Mar. Campus Universitario Mar. C/ del Dr. Aiguader, 88, Ciutat Vella, 08003 Barcelona (Spain)

E-mail / ORCID

**xrubio@ub.edu**

 <https://orcid.org/0000-0003-4428-4335>

**kmarin@ub.edu**

 <https://orcid.org/0000-0001-5588-3195>

**ccorral@researchmar.net**

 <https://orcid.org/0000-0002-0621-4590>

## ARTICLE / ARTÍCULO

# Using Data Science to evaluate Game-Based Learning in informal contexts

## La evaluación del aprendizaje basado en juegos en contextos informales mediante ciencia de datos

Xavier Rubio-Campillo<sup>1</sup>, Kevin Marín-Rubio<sup>2</sup> & Celia Corral-Vázquez<sup>3</sup>

**Abstract:** The emergence of digital Game-Based Learning (GBL) has sparked interest in assessing its efficacy. This assessment needs to consider the complex mix of narrative and interactivity typical of video games, which makes it difficult to evaluate to what extent a video game achieves its stated learning objectives. This challenge is exponentially increased when gaming sessions happen spontaneously in informal contexts, without any supervision by educators or the option to assess the players' prior knowledge and skills. This work presents a methodology for analyzing GBL experiences based on data science and the data collection functionalities offered by current game development platforms. This strategy is applied to the analysis of a social media simulator designed to promote information literacy within the video game Julia: A Science Journey. The system collected data on 436 sessions from 112 unique players over six months. The records included information on replayability, identification of fake news, and reaction times. The results suggest that players become more adept and swifter at identifying fake news through repeated games. Success in identifying misinformation is also related to the topic, with hoaxes related to scientific content being more easily recognized than those associated with political controversies.

**Keywords:** Video games, Game based learning, Information literacy, Misinformation, Data science, Critical thinking.

**Resumen:** El auge del aprendizaje basado en juegos (ABJ) digitales ha generado un interés por explorar su eficacia, ya que su compleja combinación de narrativa e interactividad hace difícil evaluar hasta qué punto un videojuego consigue alcanzar los objetivos de aprendizaje planteados. Este reto se incrementa de manera exponencial cuando la sesión de juego se produce de manera espontánea en entornos informales, sin la supervisión de educadores ni la posibilidad de evaluar los conocimientos y las capacidades previas del jugador. Este trabajo presenta una metodología de análisis de experiencias de ABJ a partir del uso de ciencia de datos y las funcionalidades de recogida de información ofrecidas por las plataformas actuales de creación de videojuegos. La estrategia se aplica aquí al análisis de un simulador de redes sociales creado para promover la alfabetización informacional, enmarcado dentro del juego Julia: A Science Journey. El sistema registró datos sobre 436 partidas realizadas por 112 jugadores distintos durante seis meses y recopiló información sobre la repetición de partidas, la identificación de fake news o la velocidad de reacción. Los resultados sugieren que los jugadores aprenden a identificar fake news de manera más efectiva y rápida a medida que encadenan partidas. El éxito en la identificación de la desinformación también está relacionado con la temática, ya que los bulos vinculados a contenido científico son más fácilmente reconocidos que los relacionados con controversias políticas.

**Palabras-Clave:** Videojuegos, Aprendizaje Basado en Juegos, Alfabetización informacional, Desinformación, Ciencia de datos, Pensamiento crítico.

## 1. Introduction

Game-Based Learning (GBL) is an emerging field in educational research. It leverages the teaching potential of games to encourage autonomous and interactive learning of complex knowledge and skills, while also fostering critical reflection on decisions made during gameplay (Gee, 2007; McGonigal, 2011). GBL studies encompass a wide variety of formats, including board games (Bayeck, 2020), role-playing games (Hammer et al., 2018), and especially video games. Due to their digital nature and interactive potential, video games have become the most studied type of game within the field (Squire, 2008), being applied to areas as diverse as history (McCall, 2016), biology (Sadler et al., 2013), and languages (Pitarch, 2018).

One of the current challenges of digital GBL is evaluating games as educational resources. This is because tracking the learning process during a gaming session is difficult due to the complexity of the interactions involved. (Connolly et al., 2009; Tahir & Wang, 2017). Previous work has focused on applying qualitative and mixed methods (documentary research, focus groups, questionnaires, etc.), which have contributed to a better understanding of games as an autonomous learning strategy (Mayer et al., 2014). However, the complexity of interactions and the current diversity of games present numerous challenges in evaluating digital GBL (Alonso-Fernández et al., 2019). Firstly, current analytical methods cannot explore the multitude of micro-interactions and decisions that occur during a gaming session; these micro-interactions, however, are crucial in characterizing the learning process with video games. Secondly, these methods do not capture the diversity of learning dynamics in video games, as each gaming session creates a unique narrative based on the player's decisions. Lastly, the methods used to date require supervised sessions and, therefore, are conducted in formal and non-formal learning contexts.

Limiting the analysis of game-based learning (GBL) processes to contexts controlled by educators poses a significant challenge in the field. Numerous authors argue that any gaming process is a learning process, regardless of its setting (McGonigal, 2011; Squire, 2021). Therefore, it can be argued that the greatest potential of GBL lies in informal contexts. Most learning dynamics with video games are not supervised by educators; instead, they occur at home on the couch, on public transportation with a mobile phone, or during social events in game sessions with friends.

One of the most popular uses of GBL in informal contexts is related to the identification of fake news. The concept of fake news gained prominence during the 2016 US elections, characterized by the spreading of erroneous or fabricated information, both on social media and traditional media outlets (Cabezuelo Lorenzo & Manfredi, 2019). Over the past few years, fake news has become widely recognized both within and beyond academic circles. It generally refers to various forms of communication, such as satire, parody, news fabrication and manipulation, as well as propaganda or deceptive advertising (Tandoc et al., 2018).

GBL appears to be a particularly suitable resource for combating misinformation and its consequences. For this reason, various digital games focused on media literacy and addressing the rise of fake news have already been developed (Fernández Galeote & Hamari, 2021). These initiatives are based on the concept of inoculation: if individuals

learn to identify fake news in a controlled setting such as a video game, they should be capable of performing the same task under real conditions on social networks (Lewandowsky & van der Linden, 2021). However, the methodological limitations discussed earlier affect the assessment of the effectiveness of these inoculation efforts. While some studies highlight their benefits, others argue that inoculation does not protect against misinformation but rather fosters general skepticism toward all sources of information, a result that diverges significantly from the original objective (Maertens et al., 2021; Modirrousta-Galian et al., 2023; Roozenbeek et al., 2022). The importance of this issue suggests that we need better methods of analysis—especially in informal contexts where most GBL occurs—if we want to identify which gaming mechanics, if any, can enhance the informational literacy of our society.

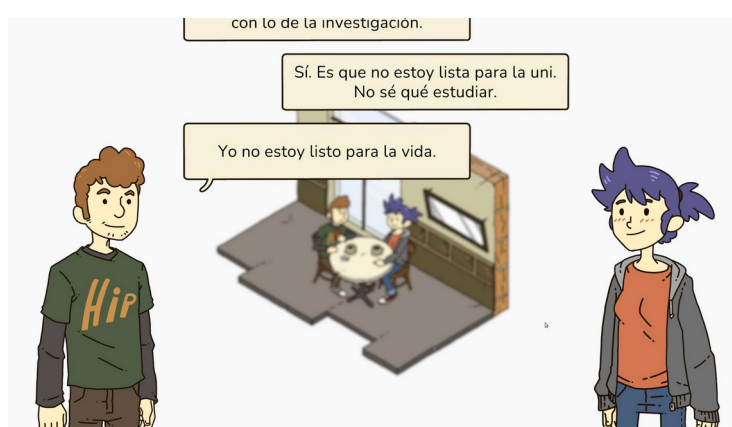
This paper presents the design and analysis of a fake news simulator in an informal learning context. This simulator is embedded as a minigame within the video game *Julia: A Science Journey* (JASJ). JASJ incorporates data science tools to gather detailed information about how players approach the game's challenges via the Unity Analytics platform. The analytical framework is applied to three research questions aimed at enhancing our understanding of informal GBL processes and inoculation against fake news: a) How does replayability influence outcome improvement? b) What impact does content have on identifying fake news? c) Is there a relationship between interaction speed and minigame outcomes?

## **2. Methodology**

### ***2.1. Design of a transformative video game***

The JASJ video game was developed by an interdisciplinary team of researchers, technicians, and artists with three objectives: a) promoting scientific culture, b) reflecting on the social impact of the COVID-19 pandemic, and c) developing a methodology to analyze GBL in informal settings. The game was implemented by a team of five using the Unity development platform and was published in Fall 2022. It is currently available as a free download for *Windows*, *Mac*, and *Linux* OS via a direct link on the official website or through the digital video game distribution platform Steam.

JASJ portrays the life of Júlia, a teenager from Majorca, in early 2020. Players will come to know Júlia through her reflections and personal relationships with friends, family, and teachers at her high school. The action unfolds just before the COVID-19 pandemic outbreak, with the plot evolving through three types of settings: a) dialogues that promote critical thinking, b) animated scenes that push the story forward, and c) minigames that delve into specific aspects linked to their use in secondary classrooms. The first two resources are useful in introducing narrative elements that enable players to empathize with the various individuals in Júlia's life and understand the impact the pandemic will have on them, with a particular focus on capturing the doubts and fears among teenagers (see Figure 1).



**Figure 1.** Dialogue at the beginning of the game. It shows content linked to the uncertainty of the future according to the perception of a teenager

## 2.2. A minigame about misinformation on social networks

Minigames are the cornerstone of JASJ's educational content, with *Quacker* standing out as a social network simulation where users must report any fake news they encounter on their wall. It is worth noting that there is currently some confusion surrounding the definition of "fake news" (Gómez-García & Carrillo-Vera, 2020; Ross & Rivers, 2018). During the development of *Quacker*, the decision was made to define "fake news" as a subset of disinformation practices focused on the dissemination of false news with fabricated, non-verifiable content, and without any mention to the sources (DeJong, 2023). Specifically, our focus is on fake news that is maliciously published and disseminated by creators who are fully aware that they are spreading deliberate falsehoods (Wardle & Derakhshan, 2018).

*Quacker* is an educational experience that simulates the social dynamics of the digital world, including the personal experiences of its users. The minigame is structured around four core concepts: misinformation, mental health, popularity, and toxicity. *Quacker* is seamlessly integrated into JASJ's story through narrative transitions in which Júlia casually uses her cell phone (e.g., while waiting for her friends). During these instances, the *Quacker* interface appears on screen, resembling a social network akin to Twitter or Instagram, where Júlia can interact with short messages posted on her wall.

The *Quacker* interface displays three main components: a) a short text message posted by a user (referred to as a "quack"), b) buttons for three possible interactions with the quack: 'like', 'dislike', and 'report', and c) the status of the game defined by Júlia's mental health, her number of followers, and the number of failures in her fake news reports (see Figure 2).



**Figure 2.** Quacker minigame user interface. The indicators of Júlia's status (mental health and popularity) have been marked with red boxes, as well as the available reaction options (like, dislike, and report).

In *Quacker*, the player is compelled to interact since there is no option to skip a quack. As in real social networks, simply viewing a post constitutes interaction. Therefore, the game design ensures that every player interaction has an effect. When a player engages with a quack, the game state changes based on three internally coded parameters:

- 1) *Fake news*. This is a binary variable (i.e., true or false) that determines whether the quack's information is a hoax, thus falling under what we commonly refer to as fake news.
- 2) *Toxicity*. The toxicity level of a quack ranges from  $-2$  to  $3$ , an interval set during the testing phase to provide a medium difficulty challenge. Interacting with a 'like' on a quack with negative values reduces toxicity within the network, thereby improving Júlia's mental health. Conversely, liking a quack with high toxicity values has a detrimental effect on it. The 'dislike' interaction reverses this dynamic: disliking a quack with negative values increases toxicity, while disliking one with positive toxicity values decreases it.
- 3) *Popularity*. The player's choices also affect Júlia's popularity, determining whether she gains or loses followers. This parameter ranges from  $1$  to  $3$ , and its effect is reversed when using the 'dislike' interaction. Like the toxicity parameter, these values were established during testing, excluding any values of  $0$  or below, reflecting the notion that every interaction within a social network awards some degree of popularity.

Each session of the minigame starts with a value of  $5$  in both popularity and mental health. The objective of the game is to react to  $10$  quacks chosen randomly out of  $30$  possible ones, without either state falling to  $0$ . Quacks can affect one or both states simultaneously, so the player must balance them. For example, liking a toxic quack will lower Júlia's mental health but increase her popularity, reflecting the typical

promotion of controversies in social media. In parallel, the second mechanic of the minigame is developed: identifying quacks as fake news using the 'Report' option. Committing three identification errors (either not reporting a quack that is fake or reporting a quack that is not) will result in failure. In all cases of failure —losing all followers, losing mental health, or receiving 3 strikes from fake news— the game ends and the player must repeat the minigame with 10 new quacks. If the player interacts with 10 quacks without meeting any of the failure conditions, they receive a score of 1 star (good), 2 stars (very good), or 3 stars (excellent), depending on the final status and on the amount of identification errors.

Fake news quacks created for *Quacker* (see Annex I for detailed information on each quack) are inspired by previously proposed definitions of fake news. Through the game states, an attempt is made to simulate the incentives found on social networks to viralize fake news instead of reporting them. The learning process focuses on reflecting on the dynamics of social media and understanding why the displayed quacks are considered misinformation. To facilitate this, *Quacker* explains the criteria for reporting quacks at the beginning of the game. Additionally, each quack is contextualized according to the reliability of the source (indicated by the name and avatar of the user who published it). *Quacker* warns the player that all opinions are allowed, but not those based on malicious false information. This is especially pertinent given the difficulty identified by previous works in differentiating between fake news and toxic opinions (Mohsin, 2020; Tandoc et al., 2018). The minigame incorporates both types of content, requiring the player to evaluate whether each quack really provides false information, or it is merely an inaccurate comment.

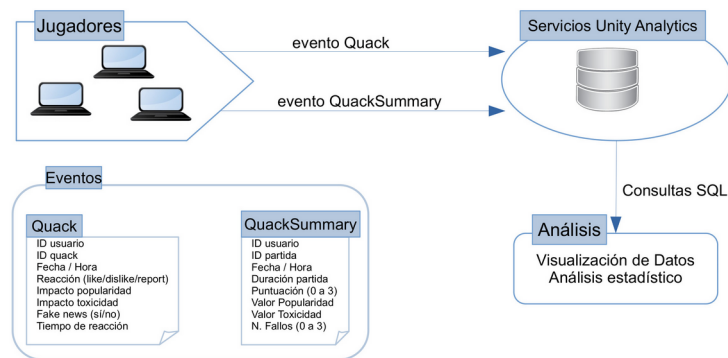
### **2.3. Data collection during gaming sessions**

Currently, most video games require permanent internet connectivity. Development companies leverage this connectivity to collect real-time information about game sessions, generating a large volume of data. This data is useful for resolving code errors (i.e., bugs), identifying problems in the game mechanics, detecting cheats, and gathering information about player behavior (Su et al., 2021). This last use is particularly relevant and is tied to the lucrative business model of microtransactions: (usually) free games that offer additional content that can be purchased within the game. The content offered to the player is selected according to the collected data, making it personalized and adapted to their interests and playing style. While this practice has been economically successful, it is considered intrusive and opaque, leading to controversy within the video game industry.

Platforms created to collect this data can also be used to analyze learning processes with video games (Alonso-Fernández et al., 2019; Cano et al., 2019; Hauge et al., 2014). The methodology involves collecting data on how players interact with the game mechanics, which, in this case, are designed to achieve specific learning objectives. Analyzing this data allows us to evaluate the extent to which these objectives have been achieved through various strategies, such as game scores or internal metrics defined by the researcher. By doing this in an informed manner, we can access large volumes of detailed information in an unsupervised way (e.g., response times between interactions, number of repetitions, interaction sequences, game schedules, etc.). Therefore, this methodology is ideal for exploring the dynamics of GBL in informal contexts, where it is not possible to choose the sample, develop questionnaires before and after the game session, or interview the players.



The research team applied this data science-based methodology to evaluate learning with Quacker, focusing on three research questions: a) What type of content is most difficult to identify? b) How does the speed of interaction affect player performance? c) How does performance improve with repeated attempts at the minigame? Figure 3 provides a summary of the data collection system; for more detailed information, see (Rubio-Campillo et al., 2023).



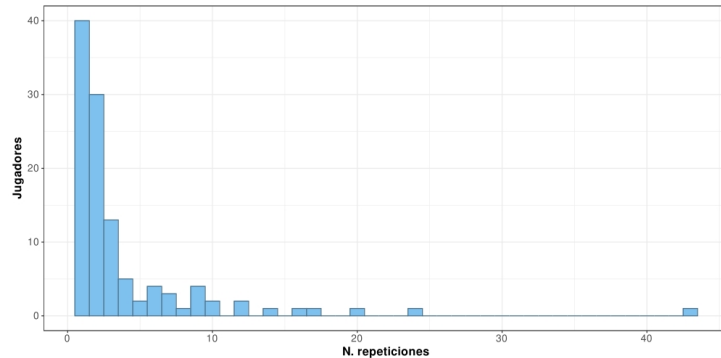
**Figure 3.** Diagram of the data collection process. As players interact with Quacker, events are sent using the Unity Analytics service and stored in a database. Researchers download recorded events using SQL queries and proceed to data analysis.

Analysis of *Quacker* was structured around two events sent from the gaming devices to a centralized database via Unity Analytics services. The Quack event collects information about a player's reaction to each specific quack presented to them, while the QuackSummary event provides information about an entire game session at the *Quacker* minigame. It is important to highlight that the initial screen of JASJ notifies the player that the game is part of a research project, and that data is collected from their gaming experience in a completely secure and anonymous manner. This screen must be accepted to continue playing.

The focus of this study on informal learning dynamics made it impossible to design an experiment with a predefined sample. Therefore, a closed data collection period was defined (November 2022-May 2023) during which data was recorded from people who voluntarily downloaded and played JASJ on their computers, without any contact or control by the research team. Over these six months, 3,565 interactions were recorded, representing a total of 436 Quacker games by 112 players, after eliminating interrupted games and fragmented information caused by communication errors.

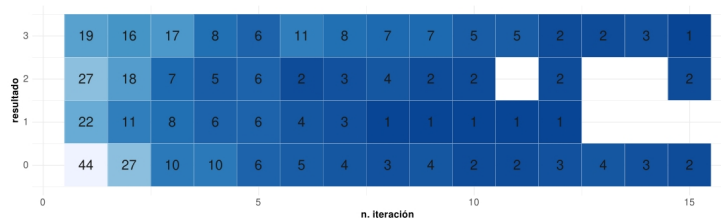
### 3. Results

Figure 4 shows the distribution of game sessions for each player. The results indicate that most players participated in 1 to 3 games of *Quacker*, while a significant number of players engaged in more than 10 games.



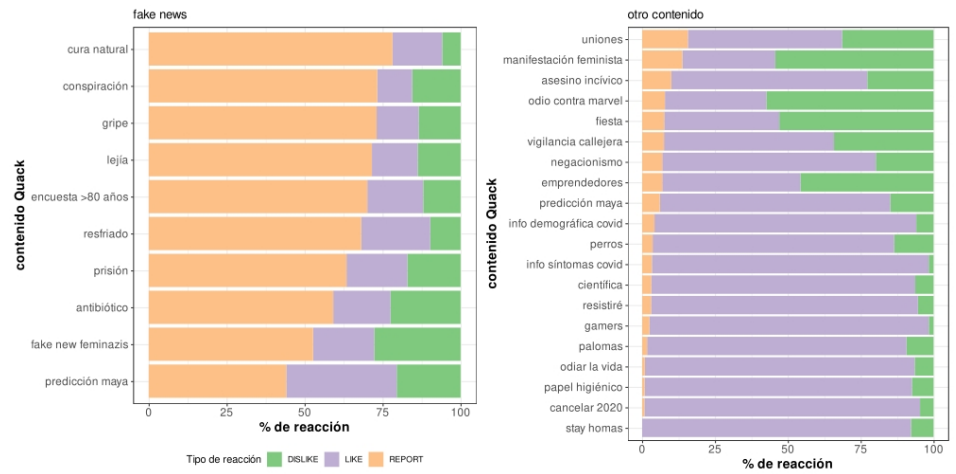
**Figure 4.** Histogram of *Quacker* games played by number of players

To examine the learning process in detail, variations in game outcomes were explored based on the number of games played by each player. If the GBL experience is properly designed, players should improve their performance through successive iterations of the game loop. In the case of *Quacker*, this should translate into better scores as more games of the minigame are played. Figure 5 shows the evolution of players' success over repeated sessions. In the initial repetitions, the percentage of 'Excellent' results (3 stars) is low, with 'Failure' (0 stars) being the most frequent outcome. However, this dynamic changes significantly from the third repetition, when the 'Excellent' result becomes the most common outcome; this pattern is maintained in subsequent iterations.



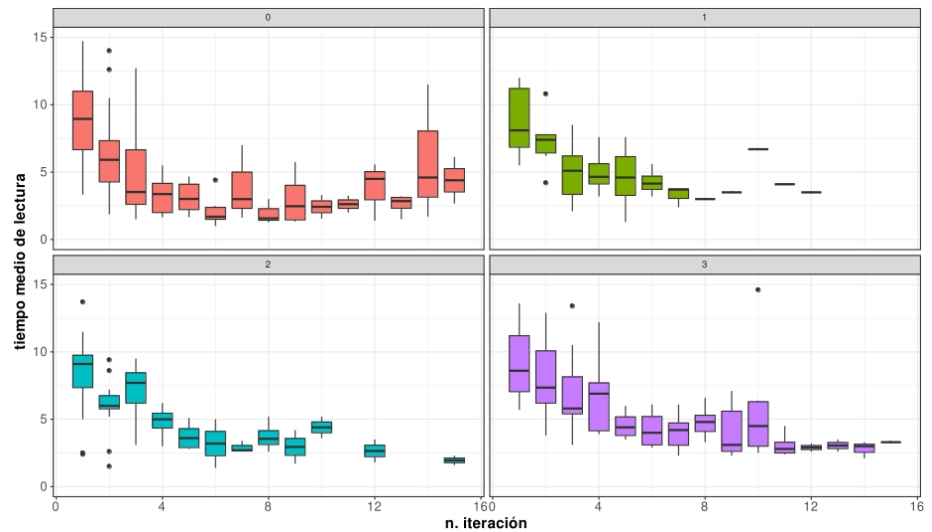
**Figure 5.** *Heatmap* showing the number of games belonging to a given iteration (x axis, limited to 15 repetitions) compared to each possible score (y axis, 0 to 3 stars)

The second question focuses on the impact of fake news and its correct identification. Figure 6 shows the percentage of reactions collected (like, dislike, report) for each of the 30 *quacks* defined in the game.



**Figure 6.** Percentage of reactions chosen for each quack. All 30 quacks are classified according to their identification as fake news to facilitate comparison

The last research question focuses on evaluating the relationship between interaction speed and player performance. Figure 7 shows the distribution of reaction times for the different iterations and outcomes.



**Figura 7.** Boxplot showing average interaction time (y axis) as a function of the iteration number (x axis), sorted out by final score (from 0 to 3 stars)

Spearman correlations between the average reaction time and the aforementioned variables suggest a strong negative correlation for the binomial 'Average reaction time' versus 'Iteration number' (-0.66), while there does not seem to be a clear correlation between speed and score (-0.02).

## 4. Discussion

Below we examine the three research questions posed above according to the set of results.

### 4.1. Iteration and learning

A typical property of GBL is replayability; that is, any game is structured as an iterative process in which the player performs a series of actions and receives feedback to inform them of their progress. From this feedback, a loop is established where the player improves their performance to move forward in the game's story.

The distribution of games shows that *Quacker* generates high interest from the players, who on average played four games of the minigame before continuing with the JASJ story. It is important to note that players can continue the main JASJ game (and therefore stop playing *Quacker*) only if they avoid failure conditions throughout the 10 quacks, regardless of how well they have done (i.e., how many stars they have earned). Thus, some repetitions are due to the need to repeat failures; the rest, however, are voluntary decisions by the player. This can be explained by several reasons: some players may want to achieve the maximum score of three stars, while others may want to explore the minigame in depth to see all the possible quacks.

This iterative improvement process is reflected in a positive correlation between the session iteration number and the number of stars achieved (0.23). We believe that this score improvement is caused by two factors: the understanding of *Quacker* mechanics and the understanding of the notion of fake news. On the one hand, transformative games like JASJ embed into the game loop content, decisions and mechanics that are closely linked to the real-world dynamics on which the player is prompted to reflect and learn. In the case of *Quacker*, as the player iterates, they will better understand the game dynamics and, therefore, improve their performance both in identifying fake news and in generating the toxicity that affects Júlia's mental health. On the other hand, the 10 quacks presented to the player during a session are randomly chosen from a pool of 30 quacks. As more games of the minigame are played, repeated quacks will appear, and the feedback the player receives will inform them about the correct identification of fake news. Thus, the combination of these two learning dynamics meets the objectives of an inoculator by improving the *Quacker* player's ability to identify fake news on social networks beyond JASJ.

### 4.2. Fake news identification

The results suggest that fake news with pseudoscientific content is easier to identify, especially when the message is linked to the COVID-19 pandemic. In contrast, fake news involving political controversies is misclassified much more frequently.

A quack inspired by a real fake news that had a significant impact on Twitter is an example of this dynamics: the supposed connection between the feminist demonstration of March 8, 2020, and the arrival of the COVID-19 pandemic in Spain. Almost half of the players did not report this quack as misinformation, and 20% of them even chose the 'like' option. Likewise, most false positives (i.e., quacks mistakenly identified as fake news) are clustered in quacks with political content. In contrast, quacks correctly identified as real information typically include humorous content,

personal reflections, and public information. This last case is worth remarking as it reveals how players use the source of information (i.e., the user who created the quack) as a valid proxy for evaluating content. Quacks made by the World Health Organization and other reputable public institutions are almost always identified as real, while similar content published by accounts of dubious origin (e.g., individuals or associations against science) is typically identified as fake news.

### **4.3. Speed of interaction**

A previous research work carried out with a smaller sample identified a negative correlation between the best result of each player and the average interaction time, understood as the average number of seconds elapsed between the presentation of a quack to the player and their reaction (Rubio-Campillo et al., 2023). The results suggested a positive relationship between reading speed and reading comprehension in a video game setting, and this is an important contribution to the ongoing debate on how reading speed impacts comprehension in digital formats (Dyson & Haselgrove, 2000). However, the analysis did not fully take advantage of the detailed information about the learning process that the system built into JASJ provides, as it only evaluated each player's best response. The results of this work extend the already published analysis by considering the relationship between three defined variables: a) speed of interaction, b) number of games played, and c) outcome.

The results show that reaction speed gradually increases with repeated games up to the ninth iteration. Beyond that point, the dynamics become difficult to interpret, likely due to the small number of players who repeat the minigame more than ten times. This number of repetitions seems illogical from the player's perspective, as the minigame is designed to be played five times, based on the pool of 30 quacks. The dynamic could be explained by the presence of players who want to see all the quacks or obtain all the achievements. These achievements are a feature of the Steam platform. When creating a game, developers propose a set of achievements published on Steam. These achievements can be related to progression (e.g., finishing a game), skill (e.g., finishing a game without failing even once), or rare events within the game (e.g., finishing a game without killing any enemies). Some players are motivated to attain all achievements (so-called completionists), and their thorough exploration of the game content likely explains the systematic repetition of the Quacker minigame.

The analysis builds on the previously mentioned positive correlation between iteration number and final outcome, suggesting that players react increasingly faster and more successfully as they repeat the minigame. The increase in reaction speed makes sense considering that some quacks will be repeated between iterations, allowing players to quickly identify their content. However, the lack of a correlation between reading speed and performance seems to contradict or at least nuance the results of the previous work. The difference in correlation values is explained by the focus of the analyses: the first analysis considered only the players' best results, discarding the rest of the attempts, while this one takes into account the entire iterative process until reaching the final score. It appears that the fastest players do not necessarily obtain better results overall; instead, as players continue to play, they react faster, making the best result, which is usually the last attempt, also the fastest.

## 5. Conclusion

One of the most important challenges of research in informal learning is evaluation in unsupervised contexts, where it is not possible to apply an experimental design to compare knowledge and skills before and after the activity. This work presents a data science-based methodology to improve the understanding of digital GBL. The richness of the data collected extends beyond the *Quacker* case study, as JASJ also collects information about its other minigames. It is worth remarking that the automatic data collection strategy is somewhat compatible with experimental designs based on questionnaires. In fact, JASJ includes an initial form for gathering player's information (e.g., socioeconomic variables, expectations, prior knowledge, or assessment of the experience). This information will be used in future works to better understand how various individual factors influence the video game learning process. Anyway, it is important to clarify that players voluntarily choose to spend their recreational time on the game, so any request for information can be perceived as a barrier and cause significant player dropout. Thus, the researcher must carefully evaluate the minimum information necessary to answer their research questions.

Furthermore, the presented methodology requires control over the video game source code, which we consider its most important limitation. The game must be designed from the beginning as an educational experience with the data collection system implemented simultaneously. Collaboration with a development studio willing to integrate such data collection for research purposes is also possible. Hence, this method cannot be applied to the study of commercial video games developed by third-party companies that do not allow code modification. Some authors have explored creating mods (i.e., modifications) to collect data in commercial games (Yee, 2014). This approach can generate detailed interaction data but is limited by the need for the player to actively install the plugin and by the possibility for game updates to affect compatibility with the developed mod.

Finally, it is important to highlight that GBL strategies are an emerging teaching resource because their format can communicate complex information through a powerful combination of narrative and interactivity. However, these elements also make analysis difficult. Therefore, the growing number of published GBL experiences should be accompanied by innovative methodological proposals that assess the educational potential of video games. These proposals should consider the diversity of avocational contexts, the typology of games, and the learning objectives, if any. The techniques necessary to analyze GBL dynamics in detail already exist but have not been widely used in the educational context until recently. Thus, beyond the specific results presented in this work, we hope this methodology contributes to a better understanding of what and how we learn when we play video games.

## 6. Acknowledgements

Analysis was conducted using the R statistics platform. Visualizations were created with the 'ggplot2' library (Wickham, 2016). Both the code and the dataset are available under an open license in [https://github.com/xrubio/JASJ\\_RELATEC](https://github.com/xrubio/JASJ_RELATEC)

This research is part of DiHealthEd 2020PANDE00072 (PANDEMIES AGAUR – Generalitat de Catalunya), and PatConfEdu PID2020-118615RB-I00 (Ministerio de



Ciencia, Innovación y Universidades). XRC is funded by the Ramón y Cajal programme RYC2018-024050-I (Fondo Social Europeo – Agencia Estatal de Investigación). Authors thank the feedback provided by two anonymous reviewers as well as the support of everyone that played Julia: A Science Journey. The game can be freely downloaded from: [https://murphystoastgames.com/sheet.php?p=julia\\_a\\_science\\_journey](https://murphystoastgames.com/sheet.php?p=julia_a_science_journey)

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## 8. Annex 1. List of Quacks implemented in the mini-game

Pop = Popularity; Tox = Toxicity

ID	Content Type	Effect	User	Quack (publication)
Cancelar 2020	Joke	Pop: 2 Tox: - 2	Cabronaxi	Ya he probado el mes gratis de 2020 y quiero cancelar la suscripción xfavor
Palomas	Joke	Pop: 1 Tox: 0	Cabronaxi	La gente se rie mucho, pero ¿te imaginas que acabamos todos confinados? Osea las palomas van a flipar en plan donde se ha metido todo el mundo.
Predicción maya	Joke	Pop: 1 Tox: 0	Cabronaxi	Seguro que esta pandemia también la predijeron los mayas xD.
Odiar la vida	Joke	Pop: 1 Tox: -1	Cabronaxi	Gente en otras redes sociales: MI VIDA ES MARAVILLOSA :D Gente por dentro: odio mi vida. Gente en Quacker: ¿odias tu vida? Yo más.
Perros	Joke	Pop: 1 Tox: 0	Cabronaxi	Ante el inminente confinamiento las perreras preparan perros para el paseo de humanos.
Gamers	Joke	Pop: 1 Tox: -1	Cabronaxi	Los gamers llevan toda la vida preparándose para esto. #Covid #Confinamiento #GamersRiseUp
Cura natural	Science	Fake New	Científicos por la verdad	¡Cura natural para la #Covid! Dr. Nanotecnólogo Sirius Quintero nos lo explica: El #Coronavirus emite 17Hz al cerebro, la solución es crear un campo de fuerza electroestática de 77Hz que anule la frecuencia del ADN enfermo. Ingredientes para el remedio: jengibre, malojillo, pimienta negra, limón y miel.
Gripe	Science	Fake New	Científicos por la verdad	La misión de Científicos por la Verdad es DESPERTAR al pueblo dormido Todos los artículos científicos sobre la Covid son falsos porque a todos los científicos les paga el gobierno. Nosotros te demostramos con ciencia alternativa que la Covid NO existe

Lejía	Science	Fake New	Donaldo Trom	Mi primo, que es médico, me dice que la #Covid es una infección. La solución es obvia, deberíamos beber lejía para limpiar nuestro cuerpo.
Científica	Science	Pop: 1 Tox: 1	Dra. Blasco	Llevo 15 años trabajando en el estudio de epidemias. Veo mucha desinformación por las redes, así que voy a intentar explicar qué está pasando en China. ¡Seguidme si os interesa! #pandemia #Covid
Negacionismo	Dispute	Pop: 1 Tox: 3	Dra. Blasco	Creo que hoy día es importante preguntarse... ¿Llamamos negacionista a todo aquel que es crítico?
Vigilancia callejera	Dispute	Pop: 2 Tox: 3	Policía vecinal	Estamos en cada calle, en cada esquina, en cada balcón... Si sales a la calle, vigilaremos que lleves mascarilla. Si alguien conoce a las personas que denunciarnos, pasadnos su perfil y nos encargaremos de civilizarla.
Asesino incívico	Dispute	Pop: 2 Tox: 1	Policía vecinal	Salir a la calle siendo portador de #Covid te convierte en asesino. Ante la duda, aíslate. #EsteVirusLoParamosUnidos #EstoNoEsUnJuego
Uniones	Dispute	Pop: 2 Tox: 0	Gobierno del buen ciudadano	¡Victoria de los trabajadores contra la patronal! En caso de confinamiento, los trabajadores tendrán derecho a saltárselo siempre que abandonen a sus familiares en casa para salir a trabajar
Papel higiénico	Joke	Pop: 1 Tox: 0	La Croqueta Indiscreta	Mucho arrasar con el papel higiénico en el súper, pero el estante del brócoli bien que ni lo tocáis, ¿eh?
Stay Homas	Music	Pop: 1 Tox: -1	La Croqueta Indiscreta	Please stay homaaa Don't want the corona ... It's okay to be alona #QuedateEnCasa #StayJomas
Fiesta	Dispute	Pop: 2 Tox: 1	La peña del moco	#MDLR ¡la EmOs liAo! Botellon Kon los R€ALes f*** polisia belnaL

Resfriado	Science	Fake New	Michael José	A los médicos se les va la olla con la Covid, es solo un RESFRIADO. Lo único que tenéis que hacer es no ir lamiendo farolas y lavaros un poco. Os dejo tontorial: Echar agua y jabón Frotar manos Enjuagar con más agua Secar al gusto
Antibiótico	Science	Fake New	Michael José	No entiendo tanta alarma con esto del virus, ¿no tenemos antibióticos? Con tomarte un par acabas con la Covid
Conspiración	Dispute	Fake New	Michael José	Nos han impuesto una gran PLANdemia llamada Covid para tenernos callados y sumisos. La Covid NO existe, siempre vas a encontrar pruebas a favor y en contra, lo que importa es lo que TÚ QUIERAS CREER. ¿Te unes a la verdad alternativa?
Predicción maya	Science	Fake New	Okí Diario	Los expertos descubren que los Mayas predijeron una gran pandemia en el siglo XXI. ¿Estamos ante el fin de la civilización?
Prisión	Dispute	Fake New	Okí Diario	#UltimaHora del #Coronavirus ¿El Gobierno está planeando encarcelar la población bajo un estado de alarma! Expertos alertan del comienzo de una dictadura socialcomunistarra.
Info demográfica Covid	Science	Pop: 1 Tox: 0	Organización Mundial de la Salud	Datos oficiales hasta la fecha: Más del 95% de los fallecidos por #Covid tenía 60 años o más, siendo los mayores de 80 los más vulnerables.
Info síntomas Covid	Science	Pop: 1 Tox: 0	Organización Mundial de la Salud	¿Cómo diferenciamos entre la #Covid y la gripe? Aunque los síntomas leves sean similares: tos seca, fiebre o fatiga. La Covid puede producir síntomas únicos como la dificultad para respirar.
Emprendedores	Dispute	Pop: 2 Tox: 2	Poma Callardo	Si tanto os quejáis de las restricciones, dejad de llorar ayudas al mismo papá Estado que os encierra. Empezad a hacer algo útil: sed emprendedores, adaptaos al mercado, invertid en cripto. Todo es cuestión de voluntad, amigo.

Manifestación feminista	Dispute	Pop: 3 Tox: 3	Poma Callardo	Si acabamos todos confinados, os recuerdo agradecerse a las feminazis de la manifestación multitudinaria del #8M
Fake new feminazis	Dispute	Fake New	Poma Callardo	¿Cuántas pruebas necesitáis? Las fotografías del #8M son suficientes para demostrar que las feminazis fueron las causantes de la gran ola de contagios en España.
Odio contra Marvel	Dispute	Pop: 2 Tox: 2	Poma Callardo	Ya estamos con otra peli de Disney que cambia de color de piel a sus protas ¡Quiten la política de mi infancia! Todo para que no se quejen los ***** ofendidos de la izquierda identitaria :)
Encuesta >80 años	Science	Fake New	tuDiario. bal	¡Que no cunda el pánico! Los mayores de 80 años no morirán de #Covid, por lo menos, este año. Así de optimistas lo afirman más de un millón de jubilados entrevistados en España
<i>Resistiré</i>	Music	Pop: 1 Tox: -1	tuDiario. bal	Más de 20 artistas unen fuerzas contra la Covid-19 con la nueva versión AGUANTARÉ 2020 #YoMeQuedoEnCasa #Aguantare #Covid19





Received: April 18, 2024  
Accepted: June 20, 2024

Author's address:

<sup>1</sup> Instituto de Investigaciones Científicas (IDIC), Universidad de la Cuenca del Plata (UCP), Facultad de Ingeniería y Tecnología, Lavalle 50, Corrientes (Argentina)


<sup>2,3</sup> Departamento de Pedagogía Aplicada y Psicología de la Educación. Campus Universitario. Edificio Guillem Cifre de Colonya. Universidad de las Islas Baleares. Ctra. de Valldemossa Km. 7'5 - 07122 Palma - Islas Baleares (Spain)

E-mail / ORCID

[claudiascre@gmail.com](mailto:claudiascre@gmail.com)

 <https://orcid.org/0000-0002-0312-3669>

[xisca.negre@uib.es](mailto:xisca.negre@uib.es)

 <https://orcid.org/0000-0003-4636-2675>

[jesus.salinas@uib.es](mailto:jesus.salinas@uib.es)

 <https://orcid.org/0000-0002-3043-8455>

## ARTICLE / ARTÍCULO

# Inclusive Education with Serious Games and User-Centered Design, Exploring the Intersection of Accessibility and Usability

## Educación Inclusiva con Juegos Serios y Diseño Centrado en el Usuario, explorando la intersección de accesibilidad y usabilidad

Claudia Screpnik<sup>1</sup>, Francisca Negre-Bennasar<sup>2</sup> & Jesús Salinas<sup>3</sup>

**Abstract:** The advancement of technology enables new resources for education. The convergence of accessibility, usability, serious games (SG) and user-centered design (UCD) enables the development of inclusive resources to respond to the needs of people with disabilities. This work aims to analyze and synthesize the developments of digital educational games, focusing on the technical aspects that facilitate their implementation in the classroom. The criteria and recommendations of the PRISMA protocol (2020) were applied to carry out the search. Keywords were used to explore the databases of Web of Science, Scopus, PubMed and 21 journals, covering the period between 2018 and 2023. In the initial investigation, 799 articles were identified, and after applying the purification process 24 publications were analyzed. The results indicate a growing and continuous interest in the topic. Current trends in the design and use of accessible video games for people with intellectual disabilities were identified, as well as their impact on learning and educational inclusion.

**Keywords:** Accessibility, Usability, Educational Games, Educational Technology, Special Education.

**Resumen:** El avance de la tecnología posibilita nuevos recursos para la educación. La convergencia de la accesibilidad, la usabilidad, los juegos serios (JS) y el diseño centrado en el usuario (DCU) posibilita el desarrollo de recursos inclusivos para responder a las necesidades de las personas con discapacidad. Este trabajo tiene como objetivo analizar y sintetizar los desarrollos de juegos educativos digitales, centrándose en los aspectos técnicos que faciliten su implementación en el aula. Se aplicaron los criterios y las recomendaciones del protocolo PRISMA (2020) para llevar a cabo la búsqueda. Se emplearon palabras clave para explorar en las bases de datos de Web of Science, Scopus, PubMed y en 21 revistas, abarcando el período comprendido entre 2018 y 2023. En la investigación inicial se distinguieron 799 artículos, y luego de aplicado el proceso de depuración se analizaron 24 publicaciones. Los resultados indican un interés creciente y continuo en la temática. Se identificaron las tendencias actuales en el diseño y uso de videojuegos accesibles para personas con discapacidad intelectual, así como su impacto en el aprendizaje y la inclusión educativa.

**Palabras-Clave:** Accesibilidad, Usabilidad, Juegos educativos, Tecnología educativa, Educación especial.

## 1. Introduction

In the digital era, the convergence of accessibility, usability, serious games (SG), user-centered design (UCD) and the needs of people with disabilities has acquired relevance in academic studies for inclusive education. From an educational perspective, SG are tools aimed at learning with a playful orientation (Bossavit & Parsons, 2018; Carrión-Toro et al., 2020). The adjective "serious" refers to its educational usefulness using fun and attractive elements. A classification defines five main categories: Edutainment, Advergaming, Edumarket game, Political games, and Training and simulation games (Alvarez et al., 2007). In addition to the SG, the UCD considers the perspectives, experiences and requirements of people with disabilities to develop educational resources and personalized learning environments (Fetaji et al., 2020; Nagalingam et al., 2020; Silva Sánchez & Rodríguez Miranda, 2018).

Furthermore, accessibility and usability in digital environments allow us to generate equality of access and participation. As SG are integrated into teaching-learning contexts, the need arises to ensure that they are inclusive, regardless of the abilities or constraints of the context (Ben Itzhak et al., 2022; Bossavit & Parsons, 2018; Bui et al., 2020; Carrión-Toro et al., 2020; Stancin & Hoic-Bozic, 2021; Tsikinas & Xinogalos, 2020). According to authors such as (Atanga et al., 2020; Holmgren, 2023), digital technology can support special education, finding applications for the inclusion of students with disabilities. Digital resources have transformed the educational scenery by improving efficiency, accessibility, and effectiveness for individualized instruction (Holmgren, 2023).

Several authors (Kamarulzaman et al., 2021; Keselj et al., 2021; Von Gillern & Nash, 2023) point out that technology is a tool for inclusive education and promotes equal opportunities, facilitating the approach of individual needs when concepts of usability and accessibility are applied. Considering the learning of mathematics as essential for life in society, it should be accessible and attractive to everyone. Teaching benefits from the integration of appropriate technology. Thus, the SG constitute a fun instrument with a significant impact on mathematics learning (Alvarado-Cando et al., 2019; De Souza et al., 2023; Fetaji et al., 2020; Ocampo-Pazos et al., 2020; Volioti et al., 2023).

This systematic literature review (SLR), framed in this complex intersection, seeks to identify opportunities and possible solutions to promote an inclusive and accessible educational environment. It uses a multidisciplinary orientation for analysis, aligned with the sustainable development goals (SDGs), specifically SDG 4: Ensure inclusive, equitable and quality education and SDG 10: Reduce inequality within and between countries (United Nations Department of Economic and Social Affairs, 2023).

This research is located in the Northeast of Argentina, a region marked by poverty and with obstacles to access to education, especially for vulnerable groups. In particular, mathematics teaching presents additional difficulties for students from disadvantaged backgrounds or with disabilities (Krüger et al., 2022; Maldonado Valera et al., 2020; Pinto, 2020).

## **2. Method**

The objective of this SLR is to analyze and synthesize digital resources. It focuses on the integration of aspects of accessibility, usability, inclusive education, SG, and UCD to improve the educational experience and promote equal opportunities, active participation and quality education.

### **2.1. Design of the investigation**

This SLR seeks to know the current state of the research area (Marín, 2022). The PRISMA method is used (Ouzzani et al., 2016; Page et al., 2021) and the methodological guidelines for analysis of scientific documents by (Sánchez-Meca, 2022). The phases used are: (1) formulation of the question, (2) definition of the study selection criteria, (3) search and location of the studies, (4) extraction of information from the studies, (5) measurement of the results of the studies, (6) synthesis and interpretation of the results and (7) writing. In addition, the recommendations of Marín (2022) are considered, identifying factors such as the need for implementation, the existence of sufficient published literature on the topic, asking if the research question can really be answered and if there is enough time to carry it out.

### **2.2. Research question**

The aim is to establish a base of knowledge and guidance to identify inclusive pedagogical practices adapted to the specific needs of the regional context, with the goal of improving educational quality and promoting equity in access to education. Following this premise, the guiding question of the study is posed: What is the impact of accessibility, usability, UCD and SG strategies in the context of inclusive education to improve learning in teaching environments?

### **2.3. Inclusion-exclusion criteria**

These criteria determine the characteristics that a study must meet to be considered in the SLR. Articles published in the last 6 years (from 2018 to 2023) that provide statistical data to allow a numerical estimation of the results are considered (Sánchez-Meca, 2022). Table 1 details the specific inclusion and exclusion criteria that will be used in this selection process.

### **2.4. Search and location of studies**

Articles published between 2018 and 2023 in the Web of Science, Scopus, PubMed databases and in 21 journals belonging to the education and technology category, open access social sciences area, in Scimago Journal & Country Rank (SJR) were reviewed. The choice of the last six years focused on addressing the most recent research, capturing current trends and advances. Qualification and coverage were considered for the databases, ensuring the identification of quality publications, relevance, and the support of peer review.

**Table 1.** Inclusion/exclusion criteria.

Topical	Inclusion Criteria	Exclusion Criteria
Publication Year	2018 to 2023	Before 2018
Methodological approach	Experience with educational SG mediated with technology (software) focused on design with accessibility, usability and UCD criteria	Experience with non-tech educational SG (not software development). Not being focused on the accessibility, usability and UCD criteria
Language	English or Spanish	Another language
Results	Explains work methodology and coherent and objectively measurable results	It does not present methodology, it does not present results, there are no elements that allow objective measurement. It does not include case studies or validation of the proposal.

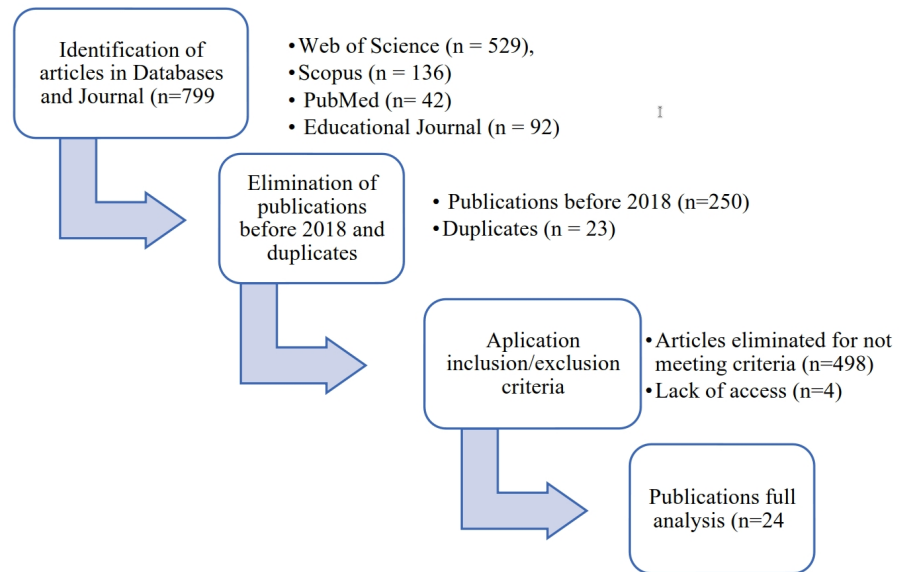
The Spanish language preference seeks to achieve research linked to the Hispanic context, and English to expand to global studies allowing an international perspective.

The following search terms were adopted: accessibility, usability, serious games, inclusive education, UCD, learning, disability, and special education. With them, the chain was set up ("accessibility" OR "usability" OR "user-centered design") AND ("serious game" OR "educational games" OR "games for learning") AND ("inclusive education" OR "inclusion education" OR "disability" OR "special education"), adapting the format to the bases consulted.

Publications were recorded in Web of Science (n = 529), Scopus (n = 136), PubMed (n = 42) and educational journals (n = 92). Publications prior to 2018 (n = 250) and duplicates (n = 23) were eliminated. Then, the inclusion/exclusion criteria were applied. Figure 1 shows the procedure for identifying studies. Figure 2 represents the key words of the research, where accessibility (red), play (green) and learning (green-yellow) emerge most strongly.

### **2.5. Extraction of study information**

Information extraction was carried out systematically, recording data such as authors, year of publication, methodologies used, main results and conclusions. It was synthesized and organized according to the objectives of the SLR (table 2).



**Figure 1.** Process diagram for searching and locating studies, following the PRISMA model.

## 2.6. Measurement of study results

To evaluate the results of the studies, metrics were used in response to the research question:

- Technology and accessibility in serious games: measures such as ease of use, adaptability, availability of aids and interoperability with other systems were analyzed.
- Impact of accessibility on education: indicators such as diversity of benefited students, equity in access, participation of marginalized groups and improvement in the educational experience of students with special needs were examined.
- Inclusion and accessibility: the effectiveness of the strategies was evaluated by measuring variables such as participation in the learning process, knowledge retention, student satisfaction, and improvement in specific skills.
- Impact on learning: measures related to academic performance, achievements in evaluations, progress in key competencies and evidence of significant learning were considered.



Of the 24 investigations included in the SLR, published in 17 countries (figure 4), 95.83% (n=23) were written in English and 4.17% in Spanish (n=1). In particular, Ecuador and Greece showed greater productivity in the subject (n=3), followed by China, Croatia, and the United States (n=2) and finally Belgium, Brazil, Canada, the Philippines, Finland, India, Indonesia, Macedonia, Malaysia, Netherlands, United Kingdom and Tunisia (n=1). Figure 4 shows that the majority, 41.67%, of the publications are located in European countries (n=10), then with 29.17% America (n=7), 25% Asia (n= 6) and finally with 4.17% Africa (n=1).

Table 2 summarizes the studies included in the SLR, detailing the substantial elements of the methodology, results and conclusions, ordered alphabetically by author.

**Table 2.** Summary of studies with details of methodologies, results and conclusions.

<b>Author (year)</b>	<b>Methodology</b>	<b>Results</b>	<b>Conclusions</b>
Alvarado-Cando et al. (2019)	Educational software based on eye tracking to assess the mathematics abilities of children with cerebral palsy. It was tested by children aged 5 and 7 years (5 students).	Four of the five students earned a higher grade using the system relative to the traditional one. Student 3 improved his grade by 18%.	Technology can improve the academic performance of students with special educational needs, highlighting their educational support.
Ben Itzhak et al. (2022)	Describes the design, development and evaluation of a set of individualized and adaptive mini-SG for visual perceptual skills. They were designed for six types of visuoperceptual skills for children with cerebral visual impairment. It was evaluated by experts.	The designed mini-games evaluated in terms of effectiveness, efficiency, operability and attractiveness indicated satisfactory results. The children's positive responses are shown, suggesting that they enjoyed the games.	These games are useful for improving children's vision and visual processing. Provides a useful perspective for the design of educational games for children with visual impairments.



<b>Author (year)</b>	<b>Methodology</b>	<b>Results</b>	<b>Conclusions</b>
Bossavit & Parsons (2018)	Pilot study that analyzes a video game co-designed with young people with autism spectrum disorders (ASD) to learn geography. It was evaluated in 5 sessions by 3 peer teams from 2 different special educational institutions, with 6 students with ASD.	They showed that the level of competitiveness of the players not only influenced the experience within the game, but also the interaction within peer teams, and that the game helped participants with ASD increase their knowledge in geography.	The students enjoyed the game, finding it easy to use. Social behaviors were positive throughout the period. They improved their knowledge in geography.
Bui et al. (2020)	Analyze the experience of playing Number Navigation Game (NNG). It uses a mixed, quantitative and qualitative methodology. It works with three cross-sectional data sets collected in different phases of NNG development. 1,168 public school students from fourth to sixth grades in four cities in Finland participated during spring 2014 .	They show that there is an advantage to having better aesthetics and value in extrinsic elements, helping to maintain the enthusiasm and situational interest of the SG.	They express an improvement in mathematical understanding. Quantitative and qualitative methods were suitable for evaluating effectiveness. They indicate that the usability and clarity of the interface made it possible to provide positive, fluid and immersive experiences.
Carrión-Toro et al. (2020)	It uses the iPlus methodology for SG design and analyzes various application cases. Its goal is to design SG with a user-centered and educational approach.	The results of a survey applied to 40 participants to evaluate the usability of educational games obtained average satisfaction scores of around 85%.	They ensure that, for the success of a SG, a methodology must be applied that incorporates fun game mechanics, high intrinsic motivation and a positive experience. The proposed metamodel allows us to understand each of the concepts used to design a SG.

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<b>Author (year)</b>	<b>Methodology</b>	<b>Results</b>	<b>Conclusions</b>
Chrisyarani et al. (2021)	RS of interactive educational games and their evaluation in terms of their quality. It was carried out through tests with experts. The heuristic method was used to evaluate the suitability of the game for end users and to identify usability and technical problems. Use descriptive research.	Minor cosmetic issues were found; however, the game is suitable for distribution. There was a slight usability problem in error prevention, obtaining an average of 2.33.	Provides information on evaluating the quality and reliability of software used in creating educational games and how these can be beneficial to education to motivate and enhance learning activity.
Dash et al. (2023)	PlutoAR is a mobile Augmented Reality (AR) interpreter designed for inclusive, cheap, immersive, portable and safe learning for children. Develops basic concepts of programming, arithmetic and computational thinking. Presents information in 3D models. 415 individuals between 10 and 45 years old participated.	They suggest that PlutoAR is a useful, easy-to-use and satisfactory application for users of different age groups.	Reliability and usability have been tested by analyzing user comments anonymously and with an unbiased approach. Reliability and usability are considered acceptable after qualitative and quantitative analysis.

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<b>Author (year)</b>	<b>Methodology</b>	<b>Results</b>	<b>Conclusions</b>
De Souza et al. (2023)	It presents a digital domino game adapted to teach multiplication to children, using the stimulus equivalence paradigm. The performance of five students with low academic level in solving multiplication operations is evaluated before and after playing.	They indicated that the students learned the relationships taught well and that there was an increase in the percentage of correct answers.	The use of additional teaching tools, such as games, can improve students' performance in mathematics.
Fetaji et al. (2020)	Investigates the impact of educational games as an instructional strategy within the Mathematics course in Secondary School. Develop a mobile math game for Android devices, as a case study, and evaluate student achievements. It uses a quantitative research methodology and a questionnaire.	Collect data before and after playing, so you can evaluate the difference between time spent and level of knowledge transferred. The functionalities and usability are evaluated in two groups of users, one with experience in computing and the other with novice users.	Contribute to identified impact factors for such systems, analysis of improvement in ease of use and usability. Ideas and recommendations are provided.

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<b>Author (year)</b>	<b>Methodology</b>	<b>Results</b>	<b>Conclusions</b>
Jebblaoui et al. (2019)	It introduces an educational game ( Choice-Game ) and proposes several scenarios to extract a specific characteristic of the student (the student's values).	The scenarios and player data collection for each are described.	An adaptive e-learning system can be used to provide them with personalized materials and recommendations that positively impact their process. It presents a limitation: using only eight scenarios cannot help collect enough data about the student.
Kaimara (2023)	It describes two data collection instruments that include detailed questionnaires on the demographic characteristics and attitudes of pre-service teachers towards inclusive education and digital educational games. The sample consisted of two hundred and sixty-five (265) undergraduate students from twenty-five Pedagogical Departments of Greek Universities.	They showed that the majority of participating pre-service teachers had positive attitudes towards inclusive education and DEGs, and saw great potential in using DEGs in inclusive educational programs. Furthermore, some barriers and challenges were identified that could hinder the effective implementation of inclusive education and the integration of SDRs into inclusive educational programs.	Provides a comprehensive and detailed overview of international efforts and current challenges related to inclusive education and digital educational games.

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<b>Author (year)</b>	<b>Methodology</b>	<b>Results</b>	<b>Conclusions</b>
Keselj et al. (2021)	Implementation of accessibility in mobile AR applications for educational purposes. It is an application for teaching geometric bodies, and focuses on making educational technologies accessible to people with disabilities. The ARGeoBody app was used in schools alongside traditional teaching methods, evaluated with 88 participants, most (but not all) of whom are typically developing students at Ivan Gundulić Primary School in Dubrovnik, Croatia.	94.7% reported that the purpose of ARGeoBody is clear, the design is functional and the functionality of the screen reader is satisfactory, it was confirmed that the design follows the third UD principle (simple and intuitive use). The first UD principle (equitable use) was satisfied, 84.2% of participants thought that the questions were clear and that the design was accessible.	It can help make content more easily accessible and understandable by providing a hands-on, immersive learning experience. They stand out: making the interface easier to use and providing accessibility options adjusting to those specific needs. Mentions the need to involve accessibility experts in planning and design to ensure the needs of students with disabilities are met.
Maqsood et al. (2018)	Series of three empirical studies to evaluate the usability and effectiveness of the educational game for young people between 11 and 13 years of age.	The game managed to significantly improve children's digital literacy and intended behavior after using it.	Positive impact on digital literacy and could be used in educational environments.

<b>Author (year)</b>	<b>Methodology</b>	<b>Results</b>	<b>Conclusions</b>
Nagalingam et al. (2020)	It focuses on creating a framework and questionnaire for evaluating educational games. The framework includes six user experience elements and the questionnaire is used to evaluate the educational game in terms of usability, immersion, game flow, player context, game system and learnability.	The validity of the questionnaire used in the study was evaluated with the content validity index (CVI). A complete list of the items and their CVIs is provided.	Evaluation helps ensure that the educational game meets the expectations and interests of the intended user and the desired educational outcomes. A suitable user experience (UX) tool for an educational game will make the work of game designers easier and help create effective educational games.
Ocampo-Pazos et al. (2020)	RS on educational video game for logical-mathematical thinking in basic education. It asks five questions on topics of software standards, design guides and evaluation methods.	Game-based learning can be developed with various technologies (AR, virtual reality, robotics and the Internet). The design should be based on the technological environment, focused on STEM (Science, Technology, Engineering and Mathematics).	Mathematical video games based on Game-based Learning allow the student to build or develop mathematical logic through experimental learning. The need to increase students' interest in STEM subjects and to promote critical thinking and active learning is highlighted.

<b>Author (year)</b>	<b>Methodology</b>	<b>Results</b>	<b>Conclusions</b>
Own et al. (2023)	A mathematical application called The Numbers was designed to compare the learning potential of preschool children and eye tracking was used to assess cognitive differences between Tangible User Interfaces (TUI) and Multi-Touch Interfaces (MTI) versions. The sample was composed of 32 students (16 girls and 16 boys) from kindergarten at Tianjin University, aged between 4 and 5 years. A pre-test was conducted using Numeracy Screener to assess their mathematical arithmetic skills.	According to the pretest results, the participants were equally divided into group T and group M, with 16 students in each group. Eighteen participants preferred the TUI version, ten participants preferred the MTI version, and four participants liked both or did not know which they preferred. They demonstrate that there are significant differences in cognitive load between both versions and that one version has better performance than the other.	The TUI version provides a higher cognitive workload, increases attention in key areas and provides greater entertainment value, which has long-term effects in promoting children's learning. The TUI version is easier to use, more interesting and more motivating for preschool children than the MTI version.
Reed et al., (2020)	Qualitative and quantitative research describing the perception and interaction of high school students in grades 6-8 with game elements incorporated into a reading assessment.	The use of gamification can be beneficial, especially for students with reading difficulties, as long as it suits their abilities and is not frustrating. The gamified reading assessment was more motivating than the traditional form of assessment.	Gamification of reading assessment can be effective in motivating students and improving their performance on the reading task, but implementation must take care of the design to ensure that the task remains relevant and faithful to the skill assessed.



<b>Author (year)</b>	<b>Methodology</b>	<b>Results</b>	<b>Conclusions</b>
Stancin & Hoic-Bozic (2021)	The objective is to analyze and evaluate the impact of digital games on inclusive learning and develop new models of digital games to support education and increasing educational inclusion.	The analysis showed that the area of social-emotional skills for students with intellectual disabilities is not sufficiently covered. There are no games available that develop this area such as the ability to recognize and understand feelings and emotional states.	Digital games can be a useful tool to improve the learning of students with intellectual disabilities, and have been used in recent research.
Tsikinas & Xinogalos (2020)	This is the SG design framework for people with intellectual disabilities or autism spectrum disorder. Proposes a SG Design Framework (GDF) to help designers and educators develop successful Ss for people with intellectual disabilities (ID) and autism spectrum disorders.	In GDF the pedagogical elements and mechanics are developed. Prototype acceptance evaluations and adjustments are carried out to improve the user experience. Usability tests serve to identify advantages and flaws by improving the game iteratively.	The game design framework is built based on elements and guidelines for people with ID and ASD, they consider that it could be used to design general purpose SG, with some modifications.
Veldkamp et al. (2022)	Research escape games and design elements such as immersion, collaboration and feedback influence learning. It was tested with 126 students between 16 and 20 years old and their gaming experience was measured, with their pre- and post-tests. Interviewed students and teachers.	The immersion element had a direct contribution to the knowledge acquired. The objects used in the game helped the students.	The framework helps educators and researchers develop and evaluate escape games that enable immersive environments such as real-world contexts related to science or socio-scientific issues and benefit learning.

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<b>Author (year)</b>	<b>Methodology</b>	<b>Results</b>	<b>Conclusions</b>
Volioti et al. (2023)	Implements AR in primary education, focusing on mathematics and active learning in the classroom. Describes the intuitive and interactive "Cooking Math" application. It focuses on cooking problems and recipes for sixth grade. A pilot study was carried out for evaluation and questionnaires and semi-structured interviews to measure the level of satisfaction and involvement.	They indicated that the app was effective and improves the learning experience for students. The SUS (System Usability Scale) questionnaires were satisfactory for all groups, with a total SUS score of 70.01.	Technology has the potential to transform education and improve learning in primary schools through the creation of a more engaging, interesting and interactive educational environment.
Von Gillern & Nash (2023)	Discusses types of disabilities and how they affect the ability to participate in a video game. Explore how to make games more accessible for people with disabilities. Suggests ways for English teachers to use video games in reading and writing skills.	Accessibility must address aspects such as visualization, hearing, mobility and cognition. Text size and color, contrast, subtitles, easy navigation, clarity of content, and access to basic instructions should be considered to ensure the inclusion of users with diverse abilities.	Video games are useful for improving English reading and writing skills. Accessibility in your design is crucial for your enjoyment. Developers must include subtitles and audio options. Universal Design for Learning promotes inclusion and learning for all.

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<b>Author (year)</b>	<b>Methodology</b>	<b>Results</b>	<b>Conclusions</b>
(Xiong et al., 2022)	Analyzes the influence of digital educational games on the creative thinking of preschool children. The digital educational game "Thinking Paradise" was developed to train children's creative thinking, and the training effects were evaluated on 102 children aged 3 to 6 years.	They showed that the digital educational game significantly improved all indicators of children's creative thinking, and that the training effect varied depending on the children's age.	When developing digital educational games for preschoolers, you should consider their age and adapt the content to strengthen their skills. The training of creative thinking from an early age and game preferences and difficulty levels for different ages are highlighted.
Yabut et al. (2019)	Development of an educational mobile game application for third grade students in mathematics (Math's Going On). 37 students participated, 25 were chosen for the scheduled session. Pre- and post-test were used. The quality of the application was evaluated according to ISO 9126. The evaluation was carried out by five mathematics teachers from the Sto Catholic School. Child.	The teacher's evaluation obtained in terms of functionality an average of 5.00 (Excellent), reliability an average of 4.40 (Very Satisfactory), usability an average of 5.00 (Excellent). Math's Going's overall satisfaction rating is 4.80, Excellent. It is useful for teachers to monitor student progress.	The app has proven to be effective for students who have different learning styles. It is suggested to implement and use as reinforcement in mathematics learning. More longitudinal studies are recommended to effectively evaluate the variables.

### **3.1. Technology and accessibility in serious games**

The results of the SLR emphasize that SG are gaining relevance in the field of education and digital learning (Bossavit & Parsons, 2018; Carrión Toro, 2022; Reed et al., 2020; Tsikinas & Xinogalos, 2020). The publications point out how through the SG, participants face individual or group challenges, putting their technical skills into practice and making responsible decisions (Carrión-Toro et al., 2020; Stancin & Hoic-Bozic, 2021; Tsikinas & Xinogalos, 2020).

Furthermore, several authors mention that usability and accessibility can be integrated into SG. The development of SG accessible to everyone, regardless of their individual abilities, promotes an enriched educational environment (Bui et al., 2020; Carrión Toro, 2022; Stancin & Hoic-Bozic, 2021).

Dash et al. (2023) and Volioti et al. (2023) highlight AR tools for the visualization of complex concepts in real time, providing immersive experiences in the real and virtual world. This technology makes it easier to understand difficult content and overcomes the limitations of traditional, static learning environments. AR enriches education by actively engaging students, allowing them to explore and apply knowledge in practical ways. This dynamic and participatory approach improves information retention, and encourages meaningful learning (Dash et al., 2023; Keselj et al., 2021; Reed et al., 2020; Volioti et al., 2023).

### **3.2. Impact of accessibility on education**

The impact of accessibility on education is significant, especially in the context of teaching people with intellectual disabilities. Various studies (Alvarado-Cando et al., 2019; De Souza et al., 2023; Fetaji et al., 2020; Ocampo-Pazos et al., 2020; Reed et al., 2020; Rodriguez-Ascaso et al., 2018; Volioti et al., 2023; Yabut et al., 2019) have highlighted the relevance of using teaching materials adapted to the student, considering how they stimulate learning, and promote sensory experiences that facilitate the development of mathematical skills (Rodriguez-Ascaso et al. al., 2018; Yabut et al., 2019). This acquisition is usually cognitively challenging where the approach focused on accessibility is essential to overcome educational barriers. These studies highlight the role of teachers in implementing adaptations.

### **3.3. User-centered approach**

Studies emphasize the relevance of game usability and clarity in the user interface to provide positive gaming experiences (Bui et al., 2020), of assistive technology in the education of students with special needs (Alvarado-Cando et al., 2019), the active participation of different stakeholders, including product owners, end users and pedagogical experts, in the game design process (Carrión Toro, 2022), the motivation of students and the improvement of their activity (Chrisyarani et al., 2021). The design must adjust its work in a user-centered approach to respond to the specific needs of the student (Bossavit & Parsons, 2018; Carrión Toro, 2022; Reed et al., 2020).

### **3.4. Inclusion and Accessibility**

The results of the SLR highlight that the technology developed with the appropriate approach allows improving the academic performance of students and constitutes an inclusive tool (Alvarado-Cando et al., 2019; Ben Itzhak et al., 2022). It promotes more positive and understanding play experiences of special needs (Bossavit & Parsons, 2018; Bui et al., 2020; Carrión Toro, 2022; Chrisyarani et al., 2021; Dash et al., 2023; De Souza et al., 2023; Fetaji et al., 2020; Jebblaoui et al., 2019; Reed et al., 2020).

### **3.5. Impact on learning**

The results obtained in most of the works show higher scores from the participants after using the application, evidencing significant learning. In general, the studies

indicate an improvement in the level of knowledge transferred, highlighting the importance of functionality and usability in the acceptance of educational games (Carrión Toro, 2022; Dash et al., 2023; De Souza et al., 2023; Fetaji et al., 2020; Jebbloui et al., 2019; Aesthetics and the improvement of extrinsic elements contributed to the enthusiasm of the players, motivating learning (Bui et al., 2020; Reed et al., 2020). Some authors recommend the use of innovative educational platforms and teacher training to achieve the implementation of technology in the classroom (Ocampo-Pazos et al., 2020; Reed et al., 2020).

#### **4. Conclusions**

The analysis to answer the research question has shown that the effective integration of accessibility, usability, UCD and SG strategies in the context of inclusive education has a positive impact on access, and at the same time improves the learning experience for the students. These strategies are fundamental to comply with the principles of quality and equity in education (United Nations Department of Economic and Social Affairs, 2023), and contribute to comprehensive training with active participation, recognizing the diversity of student abilities.

The studies reviewed show a varied and enriching perspective on the impact of SG, usability, accessibility and educational games in the academic field. The methodological and technological diversity used in these works demonstrate the complexity and breadth of this field of research. In this perspective, attention to inclusion and accessibility influences to achieve an equitable education. The ability of SG to adapt to different barriers and satisfy a variety of abilities demonstrates its potential contribution to more inclusive and accessible educational environments (Keselj et al., 2021; Reed et al., 2020; Rodríguez-Ascaso et al., 2018; Silva Sáñez & Rodríguez Miranda, 2018; Von Gillern & Nash, 2023).

Another contribution of the studies analyzed are the considerations on usability and user experience in educational technologies. Consideration of preferences and personalization emerge as critical factors for the design of technologies that truly connect with students (Alvarado-Cando et al., 2019; Ben Itzhak et al., 2023; Bossavit & Parsons, 2018; Bui et al., 2020; Dash et al., 2023; Maqsood et al., 2018; Ocampo-Pazos et al., 2020; Own et al., 2023; Reed et al., 2020; Stancin & Hoic-Bozic, 2021; Yabut et al., 2019).

Regarding the impact on learning, the positive results of several studies support the idea that the integration of SG in educational environments can generate significant improvements (Alvarado-Cando et al., 2019; Ben Itzhak et al., 2023; Bossavit & Parsons, 2018; Hoic-Bozic, 2021; Yabut et al., 2019). The combination of quantitative and qualitative methodologies offers a more complete view of effectiveness and user experience. This comprehensive approach highlights the importance of understanding academic performance, and at the same time the perception of students in the educational process (Bui et al., 2020; Nagalingam et al., 2020; Veldkamp et al., 2022; Xiong et al., 2022).

In conclusion, the analysis carried out highlights the importance of user experience and usability as fundamental pillars in the design of educational tools. The consideration of preferences and the personalization of learning experiences are basic

elements to achieve student motivation. Usability and accessibility features consolidate an inclusive approach to ensure equitable access to all students, regardless of their individual abilities.

This discussion shows the importance of an inclusive and accessible UCD in SG, to fully take advantage of the potential of technologies and achieve educational inclusion. Within the framework of this study, a solid base of knowledge and guidance has been established to identify inclusive pedagogical practices applicable to the specific needs of individuals with disabilities. The results obtained demonstrate tangible improvements in accessibility, usability and UCD in SG, thus contributing to promote equity in access to education and raising the quality of teaching in the region.

Despite the aforementioned contributions, some limitations are recognized, such as the small sample size (Alvarado-Cando et al., 2019; Bossavit & Parsons, 2018; Maqsood et al., 2018; Reed et al., 2020). The need arises for longitudinal research with exploration of new technologies for a more complete understanding of educational practices (Reed et al., 2020; Tsikinas & Xinogalos, 2020; Veldkamp et al., 2022; Volioti et al., 2023; Von Gillern & Nash, 2023; Xiong et al., 2022).

In future lines of work, it is planned to continue the deepening and detailed study of the techniques and strategies identified to formulate design principles. The purpose is to develop an application that specifically contemplates and responds to the educational needs of the local environment. This initiative seeks to facilitate the incorporation of people with disabilities into life in society through inclusive learning opportunities adapted to their individual demands.

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<https://doi.org/10.1109/HNICEM48295.2019.9073428>





Received: February 7, 2024  
Reviewed: June 24, 2024  
Accepted: July 1, 2024

Author's address:

Departamento de Didáctica,  
Organización y Métodos de  
Investigación. Facultad de  
Educación. Universidad de  
Salamanca. Paseo de Canalejas,  
169, 37008, Salamanca (Spain)

E-mail / ORCID

[jaguilarmz@usal.es](mailto:jaguilarmz@usal.es)

 <https://orcid.org/0009-0005-7218-2362>

[josecarlos.sp@usal.es](mailto:josecarlos.sp@usal.es)

 <https://orcid.org/0000-0002-8917-9814>

[fma@usal.es](mailto:fma@usal.es)

 <https://orcid.org/0000-0002-1783-8198>

## ARTICLE / ARTÍCULO

# Teachers' Perceptions of the Effects of the Digital Divide and Educational Inclusion

## Percepciones docentes hacia los efectos de la brecha digital y la inclusión educativa

Jorge Luis Aguilar-Martínez, José Carlos Sánchez-Prieto y Fernando Martínez-Abad

**Abstract:** This study seeks to analyse, through teachers' perceptions, the impact of the digital divide and the relationships of educational inclusion in the use of Information and Communication Technologies (ICT) in education. The study also aligns with Sustainable Development Goal 4 of the United Nations' 2030 Agenda, which promotes inclusive and quality education. A quantitative methodology was used, employing a specially designed and validated Likert scale to measure teachers' perceptions in three dimensions: perceptions of the digital divide's effects on teaching; perceptions of the inclusive use of technologies in the classroom and inclusive education practices in the classroom. Altogether, 790 primary-level teachers from western Honduras participated. The results indicate that perceptions are limited on the digital divide's effects among the participating teachers. Likewise, differences were found in how older teachers perceive the inclusive integration of technologies in the classroom. Furthermore, the participating teachers primarily demonstrated a theoretical understanding of inclusive education practices. These findings indicate the existence of an improved awareness and practical understanding of technological integration and inclusive strategies in the educational context.

**Keywords:** Digital Divide, ICT, Inclusive Education, Educational Technology, Inclusive Practices.

**Resumen:** Este estudio busca analizar a través de las percepciones de los docentes, el impacto de la brecha digital y las relaciones de la inclusión educativa en el aprovechamiento de las TIC en la educación. En línea con el Objetivo de Desarrollo Sostenible 4 de la Agenda 2030 de Naciones Unidas, que promueve una educación inclusiva y de calidad. La metodología utilizada fue cuantitativa empleando una escala tipo Likert diseñada ad hoc y validada, para medir la percepción del profesorado en tres dimensiones: percepción hacia los efectos de la brecha digital en la enseñanza, percepción hacia el uso inclusivo de las tecnologías en el aula y las prácticas de educación inclusiva en el aula. Participaron 790 docentes en servicio en el nivel primario en el occidente de Honduras. Los resultados indican que existe percepción limitada hacia los efectos de la brecha digital en el profesorado participante. Asimismo, se encuentran diferencias entre la forma en la que los docentes de mayor edad perciben la integración inclusiva de tecnologías en el aula. Además, en el profesorado participante se denota una comprensión principalmente teórica de las prácticas de educación inclusiva. Estos hallazgos indican la existencia de una mejorable conciencia y comprensión práctica de la integración tecnológica y las estrategias inclusivas en el contexto educativo.

**Palabras clave:** Brecha Digital, TIC, Educación Inclusiva, Tecnología Educativa, Prácticas Inclusivas.

## 1. Introduction

Currently, digital transformation in educational systems has emerged as an imperative need, particularly in Latin American countries. Governments and nongovernmental entities have expressed significant interest in modernising education by integrating digital technologies, implementing new strategies and directing national policies towards achieving the United Nations' Sustainable Development Goals (SDGs), namely seeking inclusive, equitable and quality education in line with SDG 4 (Navarrete et al., 2021): Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.

However, the reality after the COVID-19 pandemic reveals a complex and challenging landscape. UNESCO's regional report on SDG 4 compliance in Latin America indicates that the prolonged closure of schools has exerted devastating effects on the region's education systems, thereby making realisation of SDG 4 by 2030 even more challenging (UNESCO et al., 2022).

The pandemic accelerated adoption of digital tools in education while simultaneously exposing gaps in access to technology and the ability to use it effectively (García et al., 2020). This situation makes improving educational services' quality and inclusion indicators even more complex, so it is crucial to review technology integration initiatives to improve quality and inclusion within the 2030 Education Agenda framework (Lugo & Ithurburu, 2019).

In this context, teachers are at the epicentre of transformation, facing challenges that go beyond mere technological adaptation (Sosa & Valverde, 2020). Financial resources' availability and digital skills are two crucial barriers hindering the path to digital transformation and improved education quality. Economic investment in technological infrastructure and teacher training are vital aspects that require attention to ensure effective integration of digital tools in the classroom. Furthermore, disparities in access to technology between urban and rural areas, as well as socioeconomic differences, help deepen the digital divide.

The Honduran educational system is structured as levels based on students' ages and cycles: pre-basic; basic and secondary. The Honduran Ministry of Education (SEDUC, 2020) manages these levels. As noted earlier, like other systems in the region, the need to promote digital transformation processes in educational systems has increased due to the pandemic's impact in the past few years. Amid the rapid spread of the virus, the government issued Executive Decree PCM-005-2020 on March 10, 2020, initiating a state of health emergency nationwide that established a long period of school closures and an accelerated shift to virtual modalities to facilitate home schooling.

Mejía-Elvir (2021) examined the new teaching modality adopted in most Honduran schools, in which the rural context and limited access to resources resulted in a total or partial decline in educational quality due to a marked digital divide that continues to affect schools nationwide.

Although the modality taken was distance education, it had some nuances that, due to context and characteristics, did not correspond to conventional distance

education. As Delgado (2020) noted, 'Distance education during this pandemic has been complemented by emergency education (EE) analysed as emergency remote teaching, responding to a sudden change in instructional models to alternatives due to a crisis situation' (p. 2). This situation undermined the progress made to date within the 2030 Education Agenda framework (UNESCO et al., 2022).

The Honduran Ministry of Education currently lacks a measurement system that allows for obtaining valid information about students' status nationally; however, estimates and context analyses indicate significant educational setbacks in the region (UNICEF, 2020). This also makes it difficult for decision-makers to establish clear educational policies to overcome access and inclusion barriers. Regarding this, Mejía-Elvir (2021) pointed out that 'a dichotomous educational policy without clear guidelines and not systemic in the context of the crisis caused the fundamental right to education not to be fully developed and a quality process directed at Honduran society' (p. 296).

Considering these elements, this study aimed to identify teachers' perceptions of the digital divide's effects on their work, as well as perceptions of inclusive integration of technologies into the classroom and actions that favour inclusive education from an analysis of their pedagogical practices. Understanding these elements is fundamental to building an inclusive and quality educational system within the framework of achieving the SDGs by 2030.

## **1.1. Background**

### *Digital Divide*

In recent years, the digital divide has gained prominence in educational discourses and initiatives, particularly in countries of the Global South, where government entities face barriers to initiating, executing and sustaining digital transformations. Defining the digital divide and the criteria for conceptualising it varies depending on the community and context in which it is used, so no universal definition exists that works everywhere (Gallardo, 2006).

According to the Economic Commission for Latin America, 'the digital divide is the dividing line between the group of the population that already has the possibility of benefiting from Information and Communication Technologies (ICT) and the group that is still unable to do so' (ECLAC, 2003, p. 17). Another perspective also must be considered, in which the digital divide refers to the difference in the availability of resources to participate in the information age (Wenhong & Wellman, 2005).

These definitions suggest that conceptualising the digital divide could be interpreted as merely an issue of access to devices and information, and the availability of economic means understood as essential inputs to access technologies. However, other authors, such as Bezerra (2020), have posited that the digital divide refers to a socioeconomic disparity between communities with Internet access and those without, although these inequalities also can apply to all recent ICT. This view emphasises Internet access as the main component of the divide, although it must be considered that access to both components is necessary to benefit from ICT.

Regarding this phenomenon in the Latin American context, it must be considered that the digital divide is not a simple issue that can be solved through access to devices and connectivity. For several years, it has been recognised that what some authors call a second divide, or cognitive divide, exists (Larraz, 2021), 'specifically related to the "digital skills" necessary to live and work in societies characterised by the growing importance of information and knowledge, which is called digital literacy' (Castaño, 2009, p. 220). As for the use of technologies in education, the knowledge divide represents one of the most complex barriers faced by digital transformation processes and has become a subject of scientific interest in research conducted in educational technology.

Montenegro et al. (2020) argued that the digital divide reflects an important barrier to achieving true student participation and creating needed conditions of equity and equal opportunities. Similarly, other studies have highlighted that how teachers perceive the digital divide is related closely to digital literacy levels (Quezada Castro et al., 2020; Pérez-Escoda et al., 2020).

The digital divide is another reflection of social inequities (González-Motos & Bonal, 2023), so its emergence in the educational context has been exacerbated by the abandonment of face-to-face education, generating greater segregation among disadvantaged students and families (UNICEF, 2020). Considering these elements, it also has become necessary to understand teachers' perceptions of educational inclusion and practices that could favour integration of students in contexts as complex and varied as those faced by the Honduran educational system and other countries in the region with similar situations.

### *Inclusive Education*

The term inclusive education is not new in our context. For several years now, the educational field has been discussing the need for inclusive schools that adapt to today's society. Ainscow (2002) noted that historically, since the 19th century, many special education teachers have advocated for and helped design measures to support young people excluded from educational plans.

To better understand the term, what Parrilla (2002) described as the beginning of a new social consciousness about education should be examined. Some authors have agreed that no specific date exists for the emergence of inclusive education and that there is no single universal way to approach this topic in each country (Ainscow, 2005; Casanova, 2011) because countries have specific difficulties and needs in educational inclusion. For example, countries with fewer economic resources need to focus more effort on the millions of children who do not attend school. Meanwhile, in wealthier countries, the concern revolves mainly around school dropout and young people leaving the education system because they view it as irrelevant (Ainscow, 2005). Consequently, it is understood that barriers to effective inclusion in schools are different in each geographic region, as determined by economic availability and cultural factors (Cabero & Córdoba, 2009).

Thus, the relationships between the digital divide and educational inclusion notably arise in the convergence of ICT, with the potential to promote educational inclusion (Cabero & Ruiz, 2017). In the integration of technologies in the classroom, the digital divide is a barrier that educational systems face as they seek to promote digital



transformations. Teachers may have negative attitudes or perceptions on integrating technologies in the classroom (Chisango & Marongwe, 2021), which could become a barrier to digitalisation projects.

The relationships between ICT and inclusive education can be understood from two perspectives. First, use of these technologies can improve education and eliminate barriers that hinder access to culture and education for all people (Pérez, 2024). However, how these technologies are designed and structured can create accessible environments or environments that hinder access, which can promote inclusion or enhance exclusion (Cabero & Valencia, 2019).

Inclusive education and ICT converge in this research on the digital divide through the possibility of accessing or not accessing educational resources and their impact on students' learning. In this sense, from the inclusive education perspective, analysing inclusion from teachers' perceptions of strategies and adaptations in the classroom is relevant.

Thus, this study's general objective was to analyse teachers' perceptions of the digital divide and educational inclusion, as well as their impact on teaching and learning.

To address this general objective, the following specific objectives were proposed:

- Analyse teachers' perceptions of the digital divide's effects on teaching and learning activities.
- Analyse teachers' perceptions of the relationship between ICT and educational inclusion.
- Analyse teachers' perceptions of educational inclusion and the adaptations necessary to achieve it.

## **2. Methodology**

The development of this study was based on an ex post facto quantitative, exploratory and nonexperimental design, following the corresponding methodological classification guidelines. This approach was characterised by examining phenomena after their occurrence without the researcher's deliberate manipulation of independent variables (Hernández-Sampieri & Mendoza, 2010).

### **2.1. Participants**

The study included the participation of teachers from the Departments of Copán and Ocotepeque in western Honduras, all actively serving in the national public system at various primary education levels.

Data collection was conducted through a nonprobabilistic convenience sampling process that focussed on available cases in which access was possible (Hernández-Sampieri & Mendoza, 2010). Participants were selected in a way that

facilitated their access and availability, allowing for an exponential increase in the number of participants.

Altogether, the sample comprised 790 participants, all of whom were active teachers in Honduras' public educational system, specifically at the primary education level. Regarding gender distribution, 30% of the participants were men and 70% women. The participants' ages ranged from 21–65 (Mean = 38.24; SD = 10.76). Regarding their workplaces' geographical locations, 59% worked in the Department of Ocotepeque and 41% in the Department of Copán. Furthermore, 75% worked in rural communities and 25% in urban areas.

All participants gave informed consent under guarantees of their responses' anonymity and the voluntary nature of their participation in the research. The participants responded to their questionnaires through the Microsoft Forms platform, and dissemination was conducted with the support of technical officers from the HRA team and the Honduran Ministry of Education.

## **2.2. Instrument and Variables**

In addition to the sociodemographic variables mentioned above, the applied questionnaire included a self-designed Likert scale with 30 items that considered the dimensions of the study object on which the validation process subsequently was conducted. The scale of teachers' perceptions of the effects of the digital divide and educational inclusion was designed with five response options: (1) totally disagree; (2) disagree; (3) neutral; (4) agree and (5) totally agree.

This scale addressed teachers' perceptions based on three established dimensions grounded on a literature review and analysis of related studies, such as those by Gómez (2019), Kardelis et al. (2021), Montenegro et al. (2020), Pérez-Escoda et al. (2020) and Rodicio-García et al. (2020).

From this review, the following dimensions (study criterion variables) were identified: a) digital divide (effects on learning, curricular development, motivation and educational exclusion); b) relationships between ICT and educational inclusion (methodological adaptations, students' expectations, communication tools and response capacity to lack of access) and c) educational inclusion (general perceptions, students' expectations, students' participation in evaluation and group segregation in the classroom). The elements included in the third dimension were based on the Inclusion Manual developed by the University of Valladolid's Teaching Innovation Group (GID) (Torrego, 2022)<sup>1</sup>

## **2.3. Instrument Validity and Reliability**

To ensure the instrument's validity, expert judgement validation was conducted based on Hernández-Sampieri and Mendoza's (2010) definition of validity: 'the degree to which an instrument truly measures what it seeks to measure' (p. 201). Thus, experienced university professors' participation in various educational research areas was sought, as their experience provided valuable theoretical and procedural contributions.

<sup>1</sup> The instrument and the informed consent used can be reviewed at: <https://doi.org/10.5281/zenodo.10326614>

Two university professors with research experience in topics related to the scale's dimensions were recruited to evaluate the study's validity and reliability. They were sent an Excel template via email, in which they evaluated the scale items, rating them from 1 to 4 based on the following criteria: relevance (whether the item is essential or important for the study and should be included); clarity (whether the item is easily understood, i.e., its syntax and semantics are adequate) and coherence (i.e., whether the item has a logical relationship with the dimension or indicator being measured). Once the evaluators' feedback was received, the information analysis was conducted.

To analyse these data, Kendall's W coefficient of concordance was selected to calculate agreement in the evaluations of the two participating judges. The coefficient calculation was conducted generally with the evaluations of all items made by the experts. The calculation was conducted using SPSS v. 26.

According to Escobar and Cuervo (2008), considering that the value 1 indicates perfect agreement among the evaluators, a good concordance was observed in the experts' evaluations ( $W = .663$ ), indicating a high degree of agreement among the judges (Siegel & Castellán, 1995).

Seven of the 30 items were reviewed and reformulated based on the experts' observations and suggestions. Once this process was completed, the first version of the form was created to apply the consistency test to the first group of participating teachers.

To measure the reliability of the instrument used, a test-retest or temporal stability test was conducted, understanding reliability as 'the degree to which the instrument produces consistent and coherent results' (Hernández-Sampieri, 2017, p. 200).

For the test-retest, a group of 31 teachers from the Department of Ocoatepeque who were willing to participate, answering the test on two occasions 10 days apart, was selected. In line with the final study sample distribution, this group comprised 20 women and 11 men who were presented with the expert-validated version of the 30-item questionnaire.

The data analysis was conducted using SPSS version 26. To assess the test-retest correlation, the intraclass correlation coefficient (ICC) was used, which 'has been accepted as the concordance index for continuous data' (Mandeville, 2005, p. 414).

Considering the ICC interpretation (Table 1), most items presented satisfactory indicators in the ICC calculation (Substantial). However, adjustments were made to the items whose results fell within the regular range (Items 2, 9, 11, 12, 13, 21 and 23). In these cases, their wording was revised to facilitate participants' understanding. Once the process was completed, the instrument's final version was prepared for application<sup>2</sup>.

<sup>2</sup> The results are presented in the annexed table and show the substantial relationships in most cases: <https://doi.org/10.5281/zenodo.10260254>

**Table 1.** Interpretation of the Intraclass Correlation Coefficient.

Value	Interpretation
0.0 - 0.20	Slight
0.21 - 0.40	Regular
0.41 - 0.60	Moderate
0.61 - 0.80	Substantial
0.81 - 1.00	Almost Perfect

Fuente: Mendeville, 2005, p. 414

#### **2.4. Procedure and Data Analysis**

After designing and validating the scale, the information was obtained and analysed. Once the instrument was adjusted and in its final version, it was sent via email and WhatsApp to be filled out through the Microsoft Forms tool. With the support of pedagogical leaders in the area, wide participation was obtained relative to the total teacher population in the region (N = 2,608).

For the descriptive analysis of the collected data, SPSS v. 26 software was used, while bivariate inferential analyses were conducted using JASP 0.18. After analysing the distribution of responses per item, comparative analyses by dimensions were conducted considering three key sociodemographic variables: gender; age and work area (rural or urban). After verifying noncompliance of the normality assumption of the distributions in the three dimensions of the applied scale, nonparametric contrasts were applied, specifically Mann-Whitney U and Kruskal-Wallis H tests. A significance level of 5% was used when interpreting these hypothesis contrasts.

### **3. Results**

The results derived from the responses provided by the participating teachers regarding all the scale items are presented below. As evidenced in Table 2, the distribution of responses to the items indicates significant variability. The items associated with the first dimension (digital divide), Items 1 to 10, exhibited the lowest means.

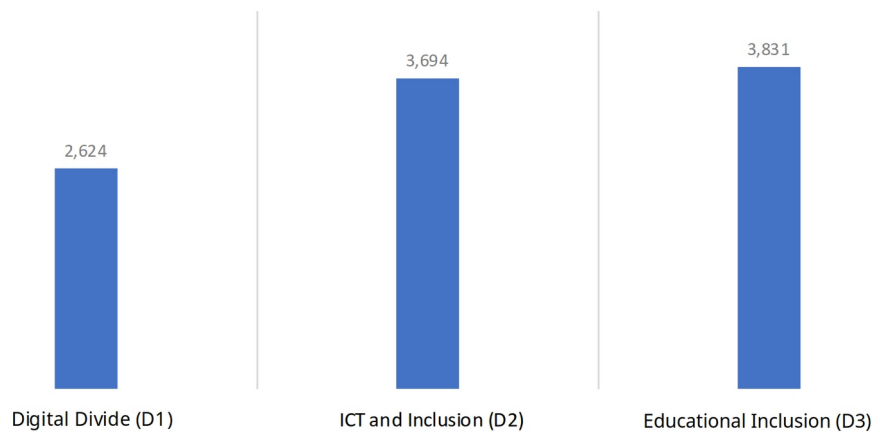
**Table 2.** Results from the applied instrument.

	<b>ITEMS</b>	<b>M.</b>	<b>D.T.</b>
1.	Limited availability of technological resources and connectivity affected students' learning continuity during 2020 and 2021.	1.63	.813
2.	Limited availability of technological resources and connectivity affected communication with students.	1.91	.997
3.	Lack of technological resources and connectivity limited the relationship between the school and families.	2.08	1.059
4.	Currently, teaching without access to technological resources and the Internet limits my tasks as a teacher.	2.64	1.245
5.	I expect less learning from students when teaching remotely.	2.03	.939
6.	The availability of access to technologies and connectivity conditions educational evaluation processes.	2.35	1.006
7.	Teaching remotely without access to ICT reduces my motivation towards my work.	3.36	1.164
8.	Teaching remotely without access to ICT affects students' motivation in activities.	2.00	.893
9.	I need specific training to make effective use of technologies in the classroom.	3.95	.887
10.	Students need prior training to use ICT.	4.28	.727
11.	ICT continues to be necessary in face-to-face modality at school.	4.20	.752
12.	It is necessary to adapt learning strategies if one of the students does not have access to ICT.	4.19	.694
13.	The teacher must find strategies to use with students who do not have access to devices and the Internet.	4.35	.714
14.	Students without access to ICT must adapt themselves to the learning pace of the rest of the group.	3.02	1.140
15.	ICT facilitates communication with students' families.	4.03	.813
16.	ICT allows me to provide quality education to more students.	3.72	.904
17.	I have lower expectations of students with little or no access to ICT.	2.79	1.01
18.	Using ICT allows for offering content adapted to students' individual needs.	3.79	.872
19.	Using ICT requires modifications to traditional classroom methodologies.	4.01	.715
20.	Students without access to ICT have fewer learning opportunities.	2.83	1.114
21.	Inclusive education is only for students with disabilities.	3.62	1.048
22.	Separating groups of 'fast' and 'slow' children is a good way to organise the classroom.	3.66	1.062
23.	Having inclusive practices in the educational centre implies more work and effort for teachers.	2.59	1.069
24.	In the classroom, I always have high expectations of all students.	4.33	.664
25.	Educational inclusion implies transforming classroom methodologies and the educational centre's functioning.	4.05	.793
26.	It is necessary to adapt the curriculum to students' interests and needs.	4.33	.644
27.	Educational inclusion requires involving all members of the educational community.	4.28	.693

ITEMS	M.	D.T.
28. Students should participate in their evaluation and grading processes.	4.10	.694
29. Students can experience significant learning outside of the educational centre.	4.09	.797
30. The 'extra' attention required by some students affects development of autonomy and socialisation skills.	3.27	1.061

Figure 1 presents the results derived from the participating teachers' responses, classified based on the instrument's three dimensions: perceptions of the digital divide's impacts on teaching (Items 1–10); perceptions of the inclusive integration of technologies in classrooms (Items 11–20) and perceptions of educational inclusion practices (Items 21–30).

The results revealed notable disparities in the means obtained between the first dimension and the following two. This suggests that the participating teachers perceived limited incidence of the digital divide's effects in their pedagogical practices. However, the differences are significantly less pronounced in Dimensions 2 and 3, in which the means obtained were comparatively similar.



**Figure 1.** Results by instrument dimensions.

Table 3 presents the results obtained from the instrument's three dimensions, revealing a significantly lower mean in the first dimension than the second and third. Furthermore, similarities were observed in the obtained means' standard deviations, indicating consistency in data dispersion across the three dimensions.

**Table 3.** Descriptive statistics by dimension.

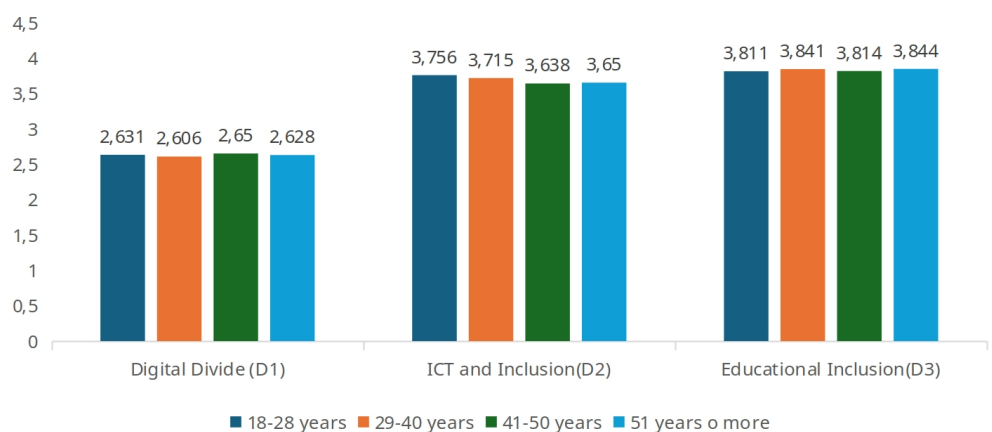
Dimension	Media	D.T.	Minimum	Maximum
Digital Divide (D1)	2.624	.388	1.30	4.100
ICT and Inclusion (D2)	3.694	.361	2.200	5.000
Educational Inclusion (D3)	3.831	.399	2.400	5.000

A comparative analysis of the results by participants' gender (Table 4) found that the male sample's means tended to be slightly lower than those of females in the three dimensions, with significant differences between both groups in perception of the digital divide's impact on teaching and the inclusive integration of technologies in the classroom.

**Table 4.** Comparison of study dimensions by gender and Mann-Whitney U test results

Dimension	Gender	Media	D.T.	W	p.
Digital Divide	Men	2.543	0.353	55140.500	<.001
	Women	2.658	0.398		
ICT and Inclusion	Men	3.658	0.369	59743.000	.054
	Women	3.709	0.357		
Educational Inclusion	Men	3.803	0.402	62033.500	.254
	Women	3.842	0.398		

To analyse the perception in the three dimensions by the participants' age groups, they were categorised into four age groups (Figure 2). The first group included teachers under age 28, the second group included those ages 29 to 40, the third group included individuals ages 41–50 and the fourth group comprised participants over 51 years old.



**Figure 2.** Results by participants' age.



The mean scores obtained among the various groups were similar, mainly in the digital divide and educational inclusion dimensions (Figure 2). In the ICT and inclusion dimension, a slight downward trend was observed in the means as age increased. Furthermore, the Pearson correlation coefficient between this second dimension and age indicated an inverse relationship ( $r_{xy}=-.101$ ;  $p=.004$ ).

Table 5 presents the Kruskal-Wallis test results from comparing these scores from the three dimensions across the four age groups. In line with previous evidence, the results revealed statistically significant discrepancies in the second dimension. This result suggests significant variability in the perception of inclusive integration of technologies in the classroom by teachers, depending on their age, with younger teachers having stronger perceptions.

**Table 5.** Scores in the three dimensions by age group in the Kruskal-Wallis test.

Dimension	H	p.
Digital Divide	2.005	.571
ICT and Inclusion	11.58	.009
Educational Inclusion	1.738	.629

Finally, an analysis of the results was conducted in relation to the educational centres' geographical location, classifying them into rural and urban environments. The results (Table 6), broken down by dimension, revealed very similar average scores in the three dimensions, with slightly stronger perceptions in all three cases by urban schoolteachers. The Mann-Whitney U hypothesis contrast found no statistically significant differences in any of the three dimensions based on the geographical locations of the participating teachers' work centres.

**Table 6.** Comparison of study dimensions by participants' geographical area and Mann-Whitney U test results.

Dimension	Zone	Media	D.T.	W	p.
Digital Divide	Rural	2.621	.383	56991.000	.879
	Urbana	2.634	.405		
ICT and Inclusion	Rural	3.691	.359	55066.500	.393
	Urbana	3.704	.369		
Educational Inclusion	Rural	3.818	.389	54829.000	.347
	Urbana	3.868	.427		

#### 4. Conclusions

Concerns over addressing the digital divide and educational inclusion are a matter of considerable importance in contemporary educational systems. Evaluating educators' perceptions of the digital divide and educational inclusion has been established as a fundamental step in promoting actions leading to educational digital transformation in any geographical area.

Conducting this research has enabled execution of an initial exploratory study aimed at discerning teachers' perceptions of the impacts of the digital divide and educational inclusion, specifically in the Departments of Copán and Ocotepeque in the western region of Honduras.

Based on the results from the instrument's first dimension, regarding the digital divide's effects in education, it can be concluded that teachers consider whether there has been continuity in students' learning, thereby perceiving few effects of the digital divide on their pedagogical practices. This issue is related closely to what Durak (2021) and Pérez-Escoda et al. (2020) have proposed, suggesting that perceptions of the digital divide are determined by the usefulness teachers find in technological resources and their digital literacy levels.

Furthermore, Cespón (2021) found that these perceptions are determined by how teachers interact with technological resources throughout their lives and the usefulness they attribute to digital tools in the teaching process, as Durak (2021) stated. Aligning with Fernández-Batanero and Colmenero-Ruiz (2016), significant differences were identified between male and female teachers' perceptions of the digital divide and the integration of technological tools in the classroom. The study results indicated that men tended to present lower averages in these aspects than women.

Regarding the instrument's second dimension, although the perception of the digital divide's effects is similar among groups, it was found that like other studies, such as Vega-Gea et al. (2021) or Suriá-Martínez (2011), teachers' age influences how they perceive integration of technologies into the classroom. This demonstrates a resistance to technology implementation among older age groups, and in this dimension, the trend of better results among female teachers than with males continues.

From this perspective, teachers notably did not perceive impacts on students' motivation due to the digital divide, as indicated by the results on Item 8. Regarding the participants' ages, although younger teachers are more affected in their work motivation by the digital divide, they perceive less need to train in technology use compared with older age groups.

Concerning the instrument's third dimension, regarding perceptions of educational inclusion, the results by gender differed from what Llorent García et al. (2020) presented, as no significant differences were observed in men and women's perceptions of educational inclusion practices. The results obtained regarding perceptions were positive and aligned with others, such as those presented by Sanhueza et al. (2012).

However, from a general perspective, the participating teachers notably have a theoretical understanding of the concept of inclusive education and its breadth, in the sense that they discarded the belief that it is only related to students with disabilities. Similarly, regarding this dimension of the instrument, it has been concluded that a belief exists among the participating group that perceives segregation of student groups based on the speed at which they learn as positive. This confirms that although a theoretical understanding of the concepts exists, this understanding does not necessarily imply practical implementation in classrooms.

The findings from this research provide valuable insights for decision-making in the Honduran educational system and other Central American countries, outlining a complex interplay between teachers' perceptions, the digital divide and educational inclusion. The reduced perceptibility of the digital divide's effects on pedagogical practices underscores the pressing need for training strategies that address the effective integration of technologies in the educational environment. The significant influence of demographic variables, such as age and gender, on these perceptions highlights the relevance of designing training programmes tailored to each demographic group's specific characteristics. Furthermore, identifying resistance attitudes in older cohorts suggests a need to address not only technical competencies, but also psychological and cultural barriers that may hinder full adoption of technology in teaching.

In this context, in general terms, teachers must manifest a positive theoretical understanding of the concept of inclusive education. Despite this conceptual advancement, the conclusion is that a favourable perception remains towards non-inclusive practices in the classroom. This finding highlights the gap between the theoretical understanding of inclusive principles and their practical application in classrooms, underscoring the need for pedagogical and awareness interventions that promote a more effective implementation of inclusive approaches in everyday educational practice.

Considering this study's conclusions, some of the study's limitations should be noted. First, the sample of participating teachers corresponded to a specific sector of the Honduran population. Despite obtaining a large sample relative to similar studies, its regional and nonprobabilistic nature makes it difficult to generalise to the country's entire population of teachers. Furthermore, in the instrument's validation, only two expert judges participated. While some authors suggest a minimum of three, no consensus has been reached on the number of judges that should participate. However, this process notably has been strengthened by applying a temporal stability test-retest.

Considering these limitations, future studies need to expand the sample of participating teachers to other regions of the country to confirm the trends observed here. Similarly, the scale's psychometric analysis needs to be deepened through specific validation and statistical confirmation studies. Finally, several lines of research can be pursued from the obtained results, primarily related to generational differences among teachers and their relationship with technology use. In this regard, delving into training needs in digital competencies is crucial, while considering cultural and generational differences between older and younger teachers.

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Received: October 25, 2022  
Reviewed: June 10, 2024  
Accepted: July 1, 2024

Author's address:

<sup>1</sup> Instituto Federal de Educação,  
Ciência e Tecnologia Farroupilha -  
Campus Alegrete - RS-377 - Km 27 -  
Passo Novo - Alegrete/- Rio Grande  
do Sul, CEP: 97555-000 (Brazil)

<sup>2,3,4</sup> Universidade Federal do Rio  
Grande do Sul. Av. Paulo Gama, 110  
- Bairro Farroupilha - Porto Alegre -  
Rio Grande do Sul, CEP: 90040-060  
(Brazil)

E-mail / ORCID

[andrea.sachete@iffarroupilha.edu.br](mailto:andrea.sachete@iffarroupilha.edu.br)

 <https://orcid.org/0000-0003-2226-3322>

[raquel.salcedo@ufrgs.br](mailto:raquel.salcedo@ufrgs.br)

 <https://orcid.org/0000-0001-9497-513X>

[alberto.canto@ufrgs.br](mailto:alberto.canto@ufrgs.br)

 <https://orcid.org/0000-0003-0822-3797>

[valdenilima@gmail.com](mailto:valdenilima@gmail.com)

 <https://orcid.org/0000-0002-7266-4856>

## ARTICLE / ARTIGO

# Indicators of adaptive learning in virtual learning environments: Systematic Literature Review

## Indicadores da aprendizagem adaptativa em ambientes virtuais de aprendizagem: Revisão Sistemática da Literatura

Andréia dos Santos Sachete<sup>1</sup>, Raquel Salcedo Gomes<sup>2</sup>, Alberto Bastos Canto Filho<sup>3</sup> & José Valdeni de Lima<sup>4</sup>

**Abstract:** Digital Information and Communication Technologies act as partners in the educational context, making it more dynamic through Virtual Learning Environments (VLEs). The adaptive system is based on technological solutions/tools, which allow the customization of teaching processes according to the student's singularities. Therefore, we conducted a systematic literature review (SLR) to elucidate which educational performance indicators best guide adaptive learning in virtual learning environments. To this end, we adopted the principles of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) as a systematic review protocol, and as operational support, we used the online tool Parsifal. The initial database search - IEEE, ACM, and Scopus - returned 276 articles. After filtering based on the protocol, 16 articles remained part of the analysis and discussion corpus. The RSL results indicate that most of the indicators used to guide activities are based on the correctness and error of the questions. This shows that there is still much to be implemented in learning adaptability in virtual environments; for a more holistic assessment of learning, it is necessary to consider an integrated set of these indicators and not just individualized analyses.

**Keywords:** Adaptive Learning, Learning Indicators, Virtual Learning Environments, Personalized teaching, Adaptive environment

**Resumo:** As Tecnologias Digitais da Informação e Comunicação atuam como aliadas ao contexto educacional, tornando-o mais dinâmico por meio dos Ambientes Virtuais de Aprendizagem. O sistema adaptativo baseia-se em soluções/ferramentas tecnológicas, que permitem customizar os processos de ensino de acordo com as singularidades do estudante. Diante disso, realizamos uma Revisão Sistemática da Literatura (RSL) para elucidar quais indicadores de desempenho educacionais são mais utilizados para guiar a aprendizagem adaptativa em ambientes virtuais de aprendizagem. Para tanto, adotamos os princípios do Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) como protocolo de revisão sistemática, e como suporte operacional utilizamos a ferramenta online Parsifal. A busca inicial nas bases de dados - IEEE, ACM e Scopus - retornou 276 artigos. Após a filtragem baseada no protocolo, restaram 16 artigos que fazem parte do corpus de análise e discussão. Os resultados da RSL indicam que a maioria dos indicadores utilizados para direcionamento das atividades se baseia no acerto e no erro das questões. Isso mostra que ainda há muito a ser implantado no que tange a adaptabilidades de aprendizagem em ambientes virtuais, pois para uma avaliação da aprendizagem mais holística, é necessário considerar um conjunto integrado desses indicadores, e não apenas análises individualizadas.

**Palavras-Chave:** Aprendizagem Adaptativa, Indicadores de Aprendizagem, Ambientes Virtuais de Aprendizagem, Ensino Personalizado, Ambientes Adaptativos.



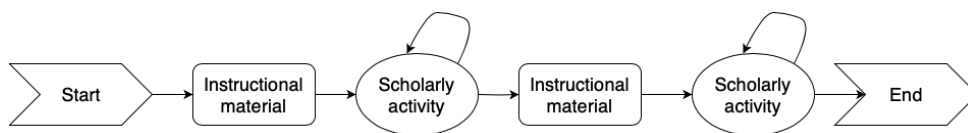
## 1. Introduction

Technological advances have provided new communication possibilities that minimize geographic barriers and become part of everyday life. Thus, digital information and communication technologies are present in all areas of knowledge, starting to act as allies in the educational context and making it more dynamic through virtual learning environments (VLEs). For Moresco and Behar (2003), VLEs are computational environments with technological resources that provide a place for students to exchange information, reflect, establish relationships, and develop projects and research. These spaces must have " a structure composed of functionalities, interface, and pedagogical proposal, enriched with symbolic codes, representations, images, sounds, movements, and synchronous and asynchronous communication devices" (Moresco and Behar, 2003).

In this way, a virtual learning environment is an online platform used for educational purposes. It encompasses environments that supplement the course, whether they are reading resources, informational websites with autonomous skills assessments, or other forms of virtual learning focused on the student. In student-centered learning, the teacher gives students more control over what, how, and when they learn a particular topic. This degree of personal interaction makes students more active in their own learning process and has demonstrated significant results (Behar, 2013).

However, the use of technological resources does not necessarily affect mastery learning. To this end, in addition to aligning the components of the Education system (curriculum and its intended results, teaching methods used, assessment tasks), it is necessary to reflect on methodologies that go beyond ready-made formulas, from a perspective in which the methods of teaching and learning are aligned with students' needs.

Traditionally, most VLEs offer the posting of assessment activities to students in a sequential manner, as demonstrated by the flow of content and activities of a teaching module in Figure 1. This module is covered to fulfill an educational objective, and to this end, it has instructional material (which can be hypertext, media, documents, among others) and activities to assess knowledge.

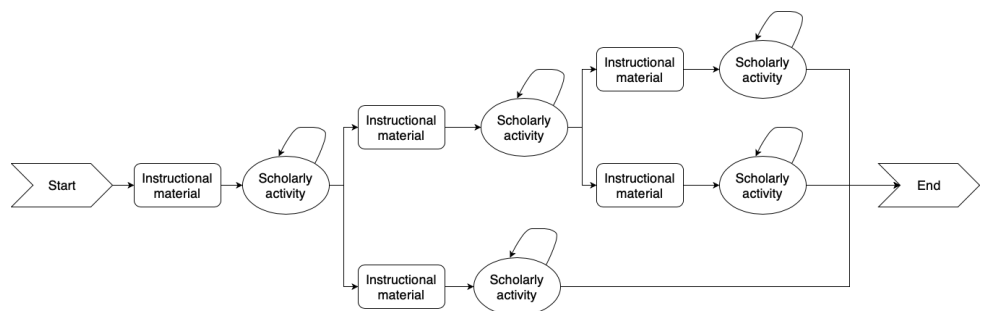


**Figure 1.** Flow of a Standard Configuration Course in Moodle.  
Source: Research data prepared by the authors.

Figure 2 demonstrates a learning trajectory that would adapt to students' difficulties and could be integrated into VLEs. In the same sense, proposals allow adaptive learning implementation (Maravanyika, Dlodlo, and Jere, 2017). Adaptive learning (Zhao & Wang, 2019) uses adaptive models, ranging from technological artifacts to intelligent systems, which can be used in collaboration with traditional teaching environments.

Adaptive learning is a form of personalization of teaching, which includes the development of learning methods that consider students' singularities and preferences to give more meaning to the construction of knowledge. According to Despotovic-Zratic (2012), adaptive learning can also be called learner-oriented platforms, adaptive environments, adaptive systems, or personalized systems.

Didactic materials with a focus on adaptive learning are designed to adapt to the knowledge levels and needs of students, seeking to increase their learning levels and allowing each student to follow their own path to achieve the objectives of the course or discipline, creating, thus, several trajectories within the same content or course.



**Figure 2.** Example of adaptive learning flow.  
 Source: Research data prepared by the authors.

Some adaptive learning proposals can be observed in the literature. For example, Moodle<sup>1</sup> supports the insertion of plugins that can offer conditional activities<sup>2</sup> implemented in the format of questionnaires<sup>3</sup>, and uses the correctness or error of questions<sup>4</sup> as a learning indicator to define whether the student can advance in the learning level. Hasibuan, Nugroho, and Santosa (2018) propose to predict student learning through a questionnaire parallel to the activity and carry out a mapping of responses based on the VARK model (Visual, Auditory, Read/Write, Kinesthetic) to reveal the strengths and learn weaknesses. Likewise, Pitigala, Gunawardena, Hirakawa, and Liyanage (2013) used a questionnaire parallel to the activities. On the answers, they apply an FLSM model (Felder-Silverman Learning Style Model) that scales the student

<sup>1</sup> Moodle is one of the most widely used virtual learning environments (VLEs) (Behar, 2013) (Gomes and Pimentel, 2021), as it offers a range of possibilities in terms of displaying content (such as hypertexts, links, documents, etc.), and a varied number of different types of assessments (forums, uploading files, quizzes, etc.). Its expansion is due to a number of reasons, including being open source, scalable and flexible in terms of configuration. It also complies with interoperability standards (Sharable Content Object Reference Model - SCORM) which makes it easier to transfer content between different platforms (Yan et al., 2010).  
<sup>2</sup> [https://docs.moodle.org/22/en/Conditional\\_activities\\_settings](https://docs.moodle.org/22/en/Conditional_activities_settings)  
<sup>3</sup> [https://moodle.org/plugins/availability\\_quizquestion](https://moodle.org/plugins/availability_quizquestion)  
<sup>4</sup> <https://www.rasch.org/rmt/rmt22g.htm>

between visual or verbal, active or reflective, sequential or global. This model allows us to evaluate the student's relationship with the learning objects and determine the best way for this student to process the information.

Li and Abdul Rahman (2018), Azzi and Radouane (2020), and Sheeba and Krishnan (2018) propose the use of probabilistic models based on student interaction with the system, which, after training, recommend customizations of activities more adapted to students.

The relevance of this Systematic Literature Review (SLR) lies in considering the multidimensionality of the human condition. It states that learning is much more complex to understand and evaluate and cannot be captured simply by checking a Boolean metric. Given this, we raise the following research question: Which educational performance indicators are most used in the literature to direct teaching and learning in a personalized and adaptive way in virtual learning environments?

Systematic reviews that relate virtual learning environments and adaptive learning are more concerned with describing the tools used to adapt learning (Fontaine et al., 2017; Zawacki - Richter et al., 2019; Martin et al., 2020 ; Li et al., 2021; Shemshack and Spector, 2020), than to uncover the set of learning indicators necessary for adaptive learning to occur. However, the bibliography has discussed a series of educational performance indicators that should also be considered (Camillo & Raymundo, 2019; Miquelante et al., 2017; Moraes, 2014). In order to encourage a discussion about the topic addressed, which is relevant to both technological and pedagogical processes in the context of online teaching and learning, this SLR aims to elucidate the research question described previously.

This SLR differs from previous ones in that it seeks to present and discuss educational performance metrics that have not yet been addressed in earlier reviews. Furthermore, this review aims to integrate multidimensional perspectives, considering the complexity of the human condition and the need for a more personalized and adaptive approach to online teaching. In this way, we hope to contribute to a significant advance in the understanding and application of educational metrics on virtual platforms, promoting more effective and student-centered teaching.

## **2. Methodology**

SLR is a mechanism for identifying, evaluating, and interpreting all available research relevant to a phenomenon of interest. An essential part is the protocol, which is the basis for planning and conducting the review. Therefore, we adopted the principles of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) as a systematic review protocol (Page et al., 2021).

The PRISMA protocol starts by searching for articles using search strings in databases and other data sources. In the case of this systematic literature review, we chose to search for articles only in scientific databases. After the search returns, the articles are filtered based on duplication, inclusion and exclusion criteria, and quality analysis. Finally, the remaining articles are those that will be part of the discussion corpus that will support the answers to the research questions investigated.

This systematic literature review has some limitations, which are listed below: (1) The search was carried out only on articles written in English, as it is a lingua franca in terms of scientific research. (2) Only articles maintained by the three digital libraries most commonly cited in other RSLs were searched: ACM Digital Library<sup>1</sup>, IEEE Xplore<sup>2</sup> e Scopus<sup>3</sup>. (3) We do not adopt Snowballing (Wohlin, 2014), a technique that allows the inclusion of references from accepted articles in the research corpus that meet the inclusion and exclusion criteria. (4) As operational support, we use the online tool Parsifal<sup>4</sup>. Below, we describe the eligibility criteria, sources of information, search strategy, study registries, and data synthesis recommended in the methods portion of the PRISMA checklist. Using the PICO (Population, Intervention, Comparison, Outcomes) strategy, we specified the characteristics of the studies to be included in our review: (a) Population: virtual learning environment. (b) Intervention: adaptive learning. (c) Results: indicator, metric, criterion, index. We created the inclusion and exclusion criteria to define the quality of the articles that would be extracted from the databases. The chosen inclusion criteria were: (1) Articles written in English. (2) Articles published from 2016 to 2023. (3) Articles that are primary studies. (4) Studies relating VLEs and adaptive learning. The exclusion criteria chosen were: (1) Articles that are not related to research. (2) Articles that are review or meta-review. (3) Article that is an older version of another article already considered in this SLR.

The inclusion criteria were established to ensure that the selected articles are aligned with the objectives and scope of the research, are written in English to facilitate understanding and global access, published in the last five years to ensure the timeliness of the information, being primary studies for providing original and relevant information, and relating VLEs and adaptive learning to meet the specific focus of the research. On the other hand, exclusion criteria were established to remove articles that do not directly contribute to the research, such as those that are not primary studies and articles that are older versions of articles already considered, thus ensuring the relevance and effectiveness of the SRL.

We perform an automatic search in information sources using a search string that combines keywords and synonyms related to two main domains: virtual learning environments, adaptive learning and their indicators, which translates into the following form:

("virtual learning environment" OR "VLE" or "distance education" OR "virtual education" OR "e-learning") AND ("adaptive learning" OR "adaptive teaching" OR "adaptive system" OR "adaptive educational learning") AND (metric OR criterion OR index OR indicator)

Once we have all the research export files, we include them in the digital data management tool Parsifal. This tool offers import options and supports the following steps: automatic checking for duplicate studies and manually labeling each article as accepted or rejected.

The combination of exported files created a database with all candidate documents. First, we delete duplicates automatically using the Parsifal tool. We then reviewed the titles and excluded articles that included the word "review" to limit them to primary studies. Afterward, we manually examined the journal names because some Scopus results were unrelated to the educational context, and we excluded articles from health, veterinary, and other areas. Therefore, we read the title and summary of the other candidates following the defined inclusion and exclusion criteria to refine the results. We did not consider articles that met at least one exclusion criterion. On the other hand, an article to be included in the final list must meet all inclusion criteria.

After applying the inclusion and exclusion criteria, we read the articles and applied a quality assessment checklist to this remaining selection. The quality assessment form had five questions and answers with specific weights: yes (2.0), partially (1.0), not specified (0.0), and no (-0.5). The questions used can be seen below:

- Q1. Does the article describe how student difficulties are measured?
- Q2. Do any metrics guide adaptive learning?
- Q3. Was the proposal implemented in the form of a digital artifact? (or is it just a proposal?)
- Q4. Is adaptive learning implemented on a VLE?
- Q5. Do the results provide qualitative or quantitative assessment data?

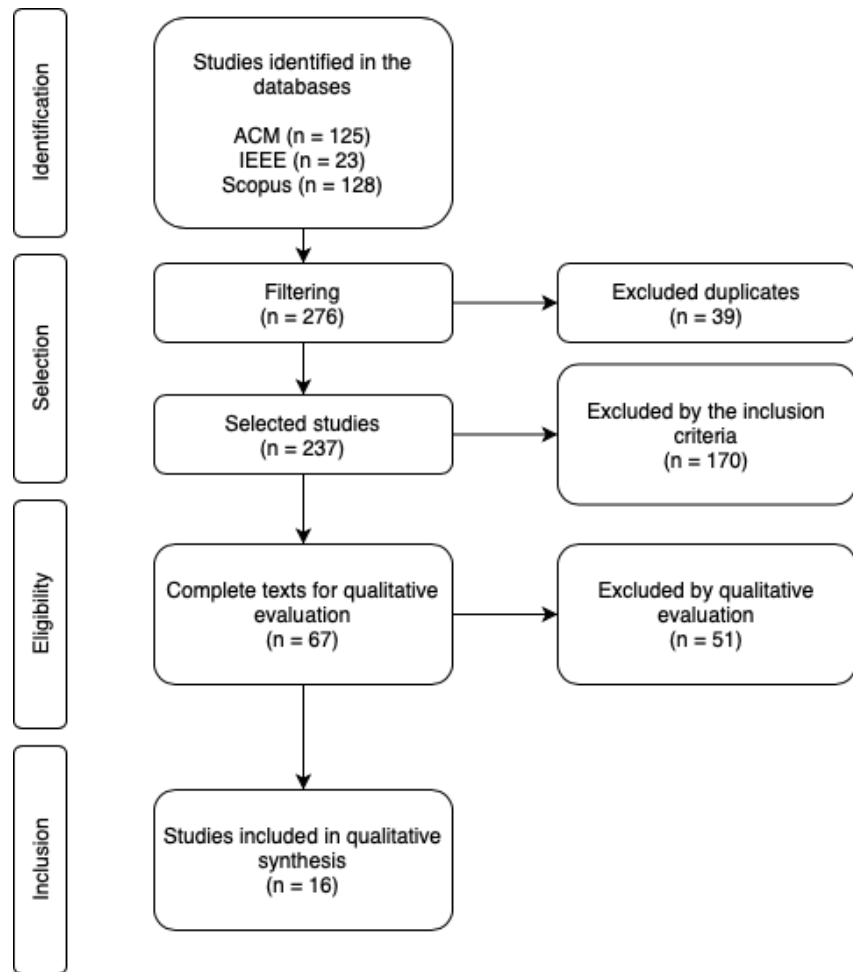
The maximum score was 10.0, calculated based on the number of questions and the answer with the greatest weight. Therefore, we accept 4.9 as the cutoff score. Consequently, after reading the content, articles with lower than the cutoff score were excluded.

After reading the studies in full, we extracted metadata and other information relevant to our research. These data include the country, year, metrics used to guide adaptive learning, the implementation of adaptive learning tools in VLEs, and which VLEs are used for this purpose.

### **3. Resultados**

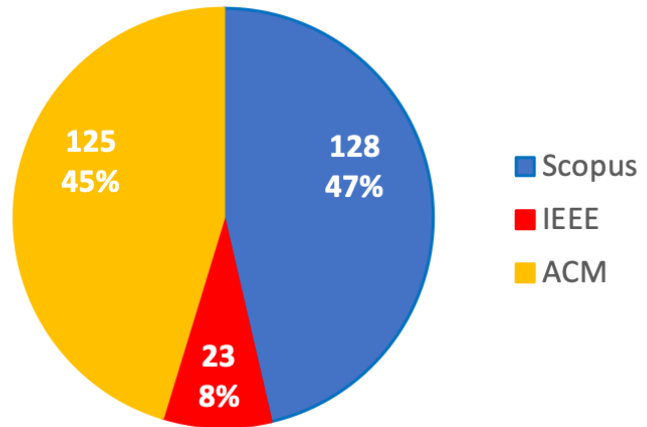
The protocol described in the previous section carried out this systematic literature review. Figure 3 illustrates the detailed process of the review phases. Initially, the automated selection returned 276 records when applying the search string to the previously mentioned databases.

Of these, 39 duplicate articles were removed. The analysis of titles and abstracts allowed the pre-selection of 67 studies that met the established inclusion and exclusion criteria. Finally, the quality checklist was applied to analyze the 67 eligible works, which resulted in 16 articles being selected.



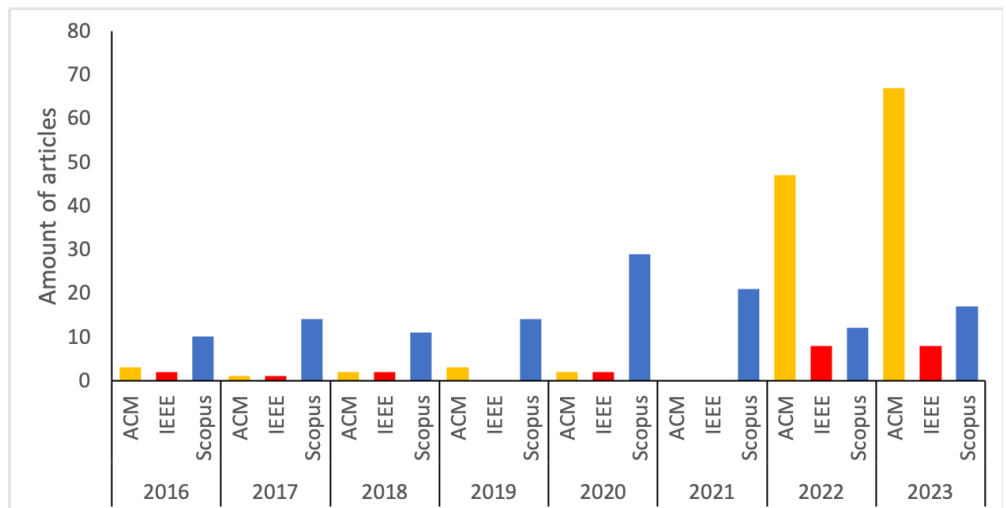
**Figure 3.** PRISMA-based systematic review protocol.  
Source: Research data extracted by the authors.

Figure 4 shows the percentage of articles retrieved by the search string in the three databases used in this study. It can be seen that the majority of articles found on the topic were returned by Scopus, possibly because many articles indexed in other databases are also present in Scopus.



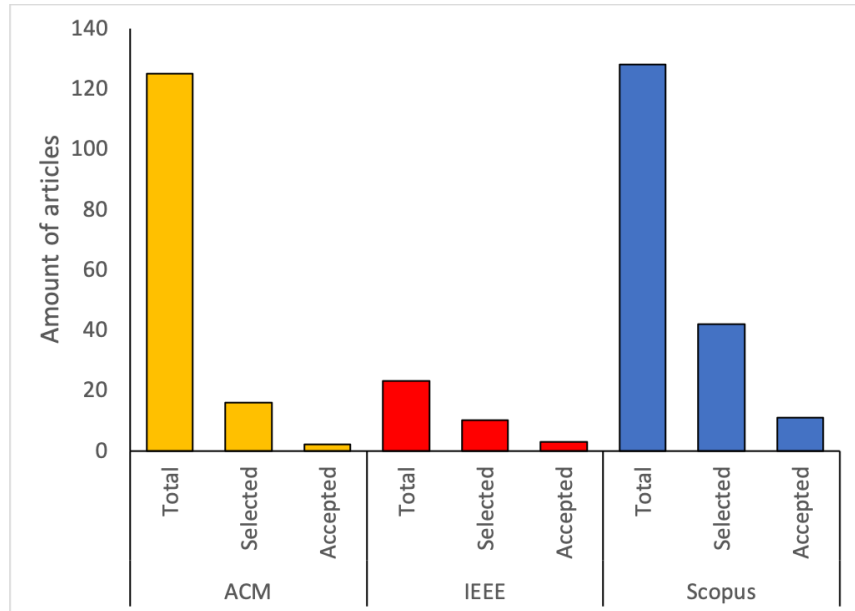
**Figure 4.** Amount of articles returned on each base.  
 Source: Research data extracted by the authors.

Figure 5 presents a stratification of the search results, organized based on the year of publication of the articles returned. A significant increase in the number of articles published on this topic is observed in 2023, indicating continued interest and research on the part of the scientific community in proposing and developing solutions in this area.



**Figure 5.** Recovered articles stratified by year.  
 Source: Research data extracted by the authors.

Figure 6 shows, by database, the number of articles selected in the first phase and, subsequently, in the second phase.



**Figure 6.** Selected articles and accepted by the criteria on the basis of databases.  
Source: Research data extracted by the authors.

At this stage, it was noticed that some studies were not aligned with the objective of the investigation. Although 2022 and 2023 recorded the largest number of articles selected by the search string, none of these works discussed the metrics used to guide adaptive learning. Thus, among the studies evaluated, 16 obtained a satisfactory score in the quality assessment, as they presented and discussed the metrics of interest to this work. These works are discussed and summarized in depth to answer the research question of this Systematic Literature Review: Which educational performance indicators are most used in the literature to direct teaching and learning in a personalized and adaptive way in virtual learning environments?

Rezaei and Montazer (2016) present an adaptive learning system that employs a clustering methodology to evaluate its impact on the quality of teaching in an e-learning course. The authors are based on learning styles and divide the grouping system into four phases: identification of group structures, classification of students into corresponding groups, detection of expiration, and group modification. The implementation of this system demonstrated improvements in both student satisfaction and academic progress, demonstrating the system's effectiveness in improving students' educational results.

The research by Dolores et al. (2017) proposed a conceptual model with six adaptability indicators in a MOOC, and based on this, they developed and administered a questionnaire to participants. The indicators are accessible teaching materials and results in evaluated activities; access to content depends on the study pace; choosing between different levels of difficulty and evaluation methods; organization by area of



interest; peer review organized according to the area of interest/training/level of experience. Dolores et al. (2017) concluded that participants emphasize two indicators: adaptation to the personal work rhythm and diversity in the levels of difficulty offered to achieve different objectives.

Su (2017) proposes a Hybrid Adaptive Learning Path Recommendation System designed to integrate individual learning styles employing fuzzy logic and suggest personalized educational itineraries. Each student's learning style is determined through a score based on their performance and success. The tool's effectiveness was evaluated in a study with an experimental group of 48 students, resulting in a significant increase in user satisfaction with the personalized service, reaching approval rates above 90%.

Hamada and Hassan (2017) developed the Enhanced Learning Style Index, which expands the Felder-Silverman model by incorporating a Fuzzy-type assessment system and adding a social-emotional dimension. This methodology was implemented in an adaptive learning system, testing it on a sample of 83 high school students. The authors concluded that the system can enable a more engaging learning experience.

Cai (2018) describes the implementation of the Intellipath platform, which was designed to enhance adaptive learning in online courses. The proposed system adjusts based on initial diagnoses and continuous evaluations (error or correct), providing an educational experience that evolves according to the student's progress. The implementation evaluation focused on criteria such as student engagement, progression, content mastery, and improvement in academic performance. The author concluded that courses that adopted the Intellipath model saw improvements in student performance and higher pass rates.

Chrysafiadi, Troussas, and Virvou (2018) investigated improving e-learning systems through a new structure for creating automated online adaptive tests, which was incorporated into two e-learning systems (one for intelligent tutoring for learning languages and one for learning programming languages). This approach uses multi-criteria decision analysis and the weighted sum model to assess the suitability of exercises for students, considering knowledge level, learning style, prior knowledge, exercise types, and learning objective, which are desirable according to Bloom's taxonomy. The proposed implementation was evaluated by computer science experts, instructors in the corresponding area, and students. The results highlighted by the authors highlighted the effectiveness of the proposed approach in reinforcing the adaptability and personalization of e-learning systems, leading to better educational results and student satisfaction.

Barbagueletta et al. (2018) propose the development of a prototype for an educational platform that offers personalized learning experiences for eighth-grade students, using multimedia activities to develop geometry skills. Metrics employed to measure student learning include learning styles, difficulty factors, success rates in completing activities, and pre- and post-test comparisons. The results demonstrated improved learning outcomes when adaptive mechanisms were applied, regardless of whether they facilitated or challenged the learning process.

The article by Shubin et al. (2019) presents an implementation model for adaptive systems in VLE using the clustering technique through neural networks. These networks are used to classify students based on their performance in the proposed activities, using the percentage of correct answers and errors and, thus, adjusting subsequent activities according to each student's level of knowledge. To this end, the researchers adopted a combination of metrics, including numerical aspects - which evaluate study time and answers to questions -, verbal aspects - capable of identifying which subtopic the student is having difficulty with -, and graphs - which focus on precision of the answers to determine the user's level of knowledge.

Dounas et al. (2019) aim to improve understanding of how adaptive systems work during the learning process and improve their design. The researchers conducted an empirical study that analyzed log files from 21 students, recorded over a three-month course offered in a VLE. Data collection included student behavior and interactions with the system, assessment results, and resources made available to students. Based on this study, they recommended four evaluation criteria: compatibility of the instructional material with the student's learning style, balance between free and guided navigation, promoting communication between students, and option for the student to disable adaptive mode.

Zaoud and Belhadaoui (2020) highlight the lack of personalization in e-learning platforms and propose the Learner Behavior Analytics model, which uses User Behavior Analytics and Artificial Intelligence to constantly adjust educational content to the student's level and learning style. Additionally, they introduce a new metric system, Score and Behavior Analytics, to evaluate student progress through scores - based on error and correct answers - and behavioral patterns - response time, clicks, and quality of answers. However, it is worth highlighting that Zaoud and Belhadaoui (2020) do not specify in their article the relevance of the metrics used, nor do they detail them extensively.

The research by Tnazefti-Kerkeni, Belaid, and Talon (2020) discusses implementing a personalized learning architecture with the following properties: a student model, learning strategies according to the student's profile, and personalized learning strategies. However, the work is in the development phase, initially focusing on finalizing the ontology applied to the student model, which uses intelligent agents to track students' activities (number of times they had to perform the exercise until they got it right). ; time on the platform; time to solve each activity) within a Learning Management System. Based on this data, the idea is to generate intelligent panels capable of automating the detection of difficulties faced by students, offering alternatives or personalized solutions.

D'aniello et al. (2020) investigate the high dropout rates from online courses, attributing the primary cause to students' lack of motivation and engagement. The authors propose an approach that involves developing a system that uses Fuzzy Cognitive Maps to verify student motivation and engagement (activity on the forum, task completion, and general interaction with the platform). Based on these metrics, personalized feedback is generated and delivered to improve students' learning experience.

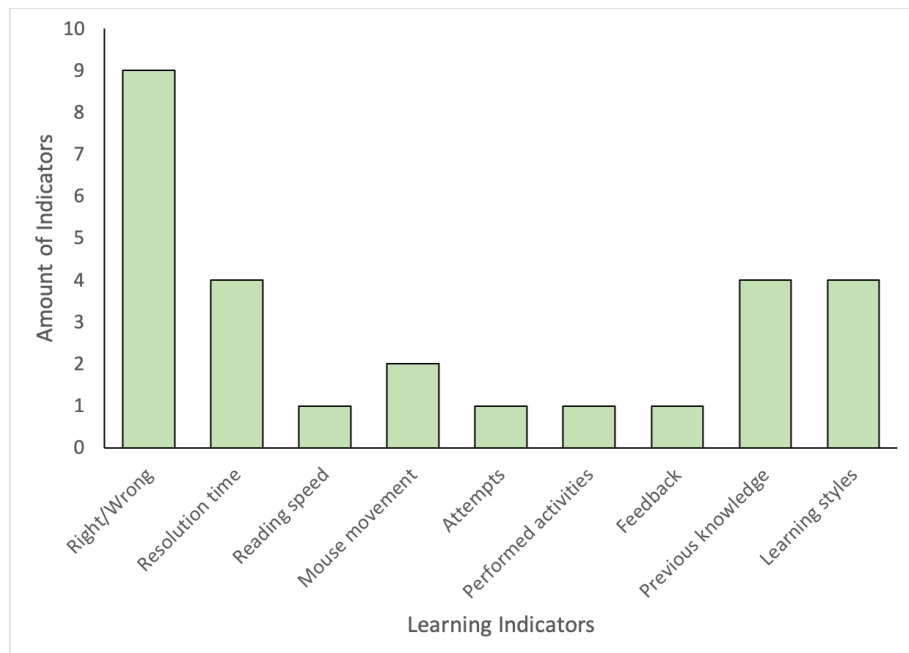
Krechetov and Romanenko (2020) describe the possibility of developing adaptive learning solutions using extensive data analysis and AI to meet personalized learning paths. The authors use a genetic algorithm to optimize learning paths based on the relationship between the level of knowledge at course completion and the time spent, aiming for maximum retention with minimum time investment. The results demonstrated significant improvements in evaluations of various educational activities.

Qu and Ogunkunle (2021) discuss the development of a simple machine learning algorithm, which considers three indices of learning attributes - prior knowledge, perceived self-efficacy, and peer collaboration - as variables in a three-dimensional space of educational effectiveness. For the authors, this approach facilitates grouping students based on their learning attributes, thus providing personalized learning experiences. The results were demonstrated by applying this algorithm, which showed the ability to create clusters of students with similar learning attributes. This clustering enabled the prediction of learning advice with varying degrees of accuracy across different clusters, showing the potential of this algorithm to improve the adaptive learning decision-making process based on comprehensive analyses of students' learning attributes.

Ghergulescu et al. (2021) propose a conceptual framework for an Adaptive Learning System enhanced by Artificial Intelligence. This framework extends the Mastery Model by incorporating subskill modeling to provide educators with deeper insights, raise students' awareness of their proficiency in different subskills, and provide more effective learning recommendations. Furthermore, the article presents BuildUp Algebra Tutor, an online platform dedicated to teaching Mathematics. To assess the effectiveness of student learning, metrics such as progress after receiving a tip and progress after making a mistake were adopted, demonstrating that accurately identifying subskills and offering structured support are effective strategies to help students answer the questions successfully. The system received positive student reviews, standing out from traditional methods regarding usefulness and ease of use. The authors also highlight the system's potential to empower teachers through intelligent dashboards that provide information about students' knowledge and progress. Additionally, survey feedback indicated a positive impact on student self-assessment metrics, including increased confidence.

Shabbir et al. (2021) propose a model that emphasizes the real-time identification and management of students' motivational states through a dual-module structure. This approach allows timely interventions, such as feedback, to increase student engagement. The authors suggested the analysis of log files as a method to detect student motivation in real time, using indicators such as reading time, mouse movement, and answers to questions, which are classified as correct or wrong, at the end of each topic. According to the researchers, the application of this model demonstrated promising results, significantly increasing student engagement and reducing school dropout rates.

Therefore, analyzing works filtered by qualitative assessment presents different indicators to assess students' knowledge and learning and thus enable adaptive learning in VLE. Figure 7 shows that most research uses error and success as a metric to decide which route the student should follow. However, this is still quite simplistic when it comes to effective student learning.



**Figure 7.** Learning indicators used.  
Source: Research data extracted by the authors.

Table 1 expands Figure 7, briefly describing the authors of the 16 articles investigated and the indicators proposed by each one for adaptive learning to happen. It is noted that some of the articles employ more than one metric to guide this type of learning.

In this way, it is observed that the mentioned works can identify and dynamically adjust educational paths, adapting the content and learning activities in response to students' performance and preferences, such as learning styles, work pace, and levels of prior knowledge, among other factors. Some of the research covered implements adaptive processes guided by more than one metric, not limited only to the correctness of activity responses. This approach allows a more detailed look at the student's training process. The results of these methodologies point to an increase in student satisfaction and learning effectiveness.

**Table 1.** Learning indicators used in adaptive learning of the 16 filtered articles and their authorship. Source: Research data extracted by the authors.

Indicators or metrics	Authors
Right/Wrong	Dolores et al. (2017) Su (2017) Cai (2018) Barbagueletta et al. (2018) Dounas et al. (2019) Shubin et al. (2019) Zaoud e Belhadaoui (2020) Shabbir et al. (2021) Ghergulescu et al. (2021)
Resolution time	Zaoud e Belhadaoui (2020) Krechetov e Romanenko (2020) Tnazefti – Kerkeni et al. (2020)
Reading speed	Shabbir et al. (2021)
Mouse movement	Zaoud e Belhadaoui (2020) Shabbir et al. (2021)
Attempts	Tnazefti – Kerkeni, Belaid e Tailon (2020)
Performed activities	D'aniello et al. (2020)
Feedback	Ghergulescu et al. (2021)
Previous knowledge	Chrysafiadi et al. (2018) Qu e Ogunkunle (2021) Chrysafiadi et al. (2018) Dolores et al. (2017)
Learning styles	Rezaei e Montazer (2016) Hamada e Hassan (2017) Chrysafiadi et al. (2018) Barbagueletta et al. (2018)

#### 4. Discussion

Although it is a promising proposal, especially today, when remote teaching and distance learning are in evidence, the result of this Systematic Literature Review shows us that the digitalization of teaching is not being used within the context of adaptive learning, as it is still We checked the learning assessment in the same way as always, using, most of the time, only the correctness of the answers. This form of evaluation goes back to a past of Cartesian thinking.

Since the 19th century, the concept of assessment has prevailed along the lines of logical reasoning and memorization. The first attempt at what would become adaptive learning was developed in the 1950s with the work of Skinner (1970). The author created a teaching machine that focused on incremental skill building. The machine adapted, offering new questions to students based on previous correct answers. It also provided students with immediate feedback and allowed them to advance at their own pace.

Thus, the results reveal that adaptive learning is still influenced by a historical evaluation factor associated with a particular caution about the complexity of implementation. As for historical issues, 19th-century pragmatism influenced Skinner's first proposals for adaptive learning, which attempted, in a certain way, to mechanize (self)learning. The learning assessment was carried out based on the students' mistakes and successes, as the binary decision was mechanically more accessible to the development of the proposal.

What we recognize as adaptive learning technology originates in the development of artificial intelligence during the 1970s. Researchers began developing systems that could mimic the teacher's experience. Although the systems that resulted from this early work had some success, the computing power and artificial intelligence technologies of the time were not advanced enough for complex intelligence or widespread use.

However, the programming implementation of adaptive learning is still essentially binary, which means that "new" proposals still use a Boolean choice model that dates back to its first proposition. Therefore, error and success are still the predominant metrics due to the nature of programming languages, which are based on conditional deviations. In addition, other factors can be viewed, still trying to avoid complexity in developing solutions. The use of time (spent during and completing activities) as a complementary factor to verify learning refers to learning management in terms of discrete time, allowing the observation of the student's action in integer quantities.

In practical work and future investigations, one must consider the advancement of available processing power, rapid system development methodologies, and artificial intelligence that reach unprecedented levels of complexity and sophistication. This supports the implementation of more complex adaptive learning models. Such models must consider different aspects of students' knowledge and learning in correlation to consider the student a subject of their own educational path. This way, he will be evaluated for his complete training process and not just for his right or wrong answers in activities and assessments.

## 5. Conclusions

Adaptive learning is a teaching and learning method that considers difficulties and pace individually. It is based on the premise that the educational object can be adapted to the specific needs of the student. For this to occur, the algorithms present in the ICTs must be remodeled because as the user interacts with the platform, the system updates dynamically, providing the student with personalized guidance.

Considering that each person has their own way and time for learning and highlighting that they seek to adapt their own ICTs to assist in this process, this work sought to find in the existing literature, between the years 2016 and 2023, the indicators most commonly used to guide adaptive learning in virtual learning environments.

According to the work reviewed in this SRL, there is ample room for implementing learning adaptations in virtual environments. This is because the indicator widely used to guide adaptive learning consists of correct and incorrect answers. Learning cannot be reduced to such a reductionist metric that it does not give importance to social and emotional issues directly affecting the cognitive. This highlights the pressing need to seek and integrate a set of new metrics to promote a more comprehensive adaptation of learning, which can take into account more humanized issues.

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Received: January 28, 2022  
Reviewed: November 11, 2023  
Accepted: March 7, 2024

Author's address:

<sup>1</sup> Universidad Pontificia de Comillas.  
C. de Alberto Aguilera, 23, Centro,  
28015 Madrid (España)

<sup>2</sup> Universidad CEU San Pablo. C. de  
Julián Romea, 23, Chamberí, 28003  
Madrid (España)

E-mail / ORCID

[avdelgado@comillas.edu](mailto:avdelgado@comillas.edu)

 <https://orcid.org/0000-0003-2158-1214>

[larram@ceu.es](mailto:larram@ceu.es)

 <https://orcid.org/0000-0001-6271-3821>

## ARTICLE / ARTÍCULO

# DEIFDC framework: Evaluation of Digital Education deployment in Peru in the midst of the Covid-19 pandemic

## Marco DEIFDC: Evaluación del despliegue de la Educación Digital en Perú en plena pandemia de Covid-19

Ana Victoria Delgado Martín<sup>1</sup> & José Marí Larrú Ramos<sup>2</sup>

**Abstract:** Digital Education is a key factor to bring developing countries up to speed so they are able to compete under the new rules of the Digital Economy. The Covid-19 pandemic crisis has made more evident the need to implement a global educational strategy where all children can be prepared to learn in a digital environment independently of their country and birth condition. In this research, a Digital Education Index for Developing Countries (DEIFDC) has been defined and applied for the Peruvian case. The construction of the index is based on relevant variables organized in three levers to determine Peru's capacity to better prepare current primary school children to acquire the competences needed in a 21st century workforce. The results show good development on pedagogical capabilities and students' readiness but only adequate maturity on the development of schools' infrastructure. Peru's slow digital development, in comparison to other countries in the region, is distressing the availability of high-skilled labour, digital GDP growth and digital services productivity hence major efforts will need to be undertaken to guarantee Peruvians upgrade to a digital prepared society.

**Keywords:** Digital education, Developing countries, Digital economy, Digital index, Social impact.

**Resumen:** La Educación Digital es un factor clave para que los países en vías de desarrollo puedan competir bajo las nuevas reglas de la Economía Digital. La crisis de la pandemia Covid-19 ha hecho más evidente la necesidad de implementar una estrategia educativa global donde todos los niños puedan estar preparados para aprender en un entorno digital independientemente de su país y condición de nacimiento. En esta investigación se ha definido y aplicado un Índice de Educación Digital para Países en Desarrollo (DEIFDC) para el caso peruano. La construcción del índice se basa en variables relevantes organizadas en tres palancas para determinar la capacidad del Perú para preparar mejor a los actuales niños de primaria para adquirir las competencias necesarias en una fuerza laboral del siglo XXI. Los resultados muestran un buen desarrollo en las capacidades pedagógicas y la preparación de los estudiantes, pero sólo una madurez adecuada en el desarrollo de la infraestructura de las escuelas. El lento desarrollo digital de Perú, en comparación con otros países de la región, está poniendo en peligro la disponibilidad de mano de obra altamente cualificada, el crecimiento del PIB digital y la productividad de los servicios digitales, por lo que será necesario realizar grandes esfuerzos para garantizar que los peruanos se conviertan en una sociedad preparada para el mundo digital.

**Palabras-Clave:** Educación digital, Países en desarrollo, Economía digital, Índice digital, Impacto social.

## 1. Introduction

Education is a human right and one of the strongest instruments for development as it contributes to reduce poverty and improve health, equality and peace (United Nations, 1948). For individuals and societies, education promotes employment, poverty reduction, economic growth and social cohesion (World Bank, 2020).

The importance of Education has been reflected in the Agenda 2030 for Sustainable Development adopted by the United Nations General Assembly, where the specific development goal number 4 has been dedicated to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. Target 4.4, described as substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship, is directly related to Digital Education (United Nations General Assembly, 2015).

2020 was a year of profound changes at social, economic and educational levels due to the Covid-19 pandemic (Unesco, 2020). 1,5 billion children and youngsters were displaced out of school with diverse consequences in terms of their learning progress, nutrition support and subsequent enrolment continuity. Specifically, in Latin America and the Caribbean more than 165 million children have lost an average of 158 school days during 2020 hindering in-person instruction (Petri C. et al. 2021). In vulnerable environments, the current digital divide made evident that those with less technical resources were unable to keep up with their standard learning process (Unicef et al., 2020) and have lost at least one year of educational development.

However, as important as Digital Education has demonstrated to be during the pandemic crisis, it should not be considered as a backup instrument to respond in case of school closure but as a means to prepare children at early stages of education to acquire the competences that will be needed in a new Digital Economy (Riviello, R., 2020). In this sense, Digital Education prepares children for the Industry 4.0 revolution (Kask. M. et al., 2021) as well as it enhances their learning experience by introducing innovative, collaborative tools and new social experiences (Luckin et al., 2012); moreover, it prepares children for advanced STEM education, increasing the number of children who will develop a career in programming, data analysis, cybersecurity or cloud management.

In developing countries, Digital Education is even more relevant because it can improve the teaching and learning processes and introduce the basis necessary for producing a technologically proficient workforce that might transform in the next 10-15 years the composition of the labour market (Kalolo, J.F., 2018). In Latin America, the expansion of education has been very significant in recent decades, but the degree of inequality remains relevant, as the creation of human capital is still dependent on the socio-economic origin of the families and education is not contributing as an equaliser factor, especially in Peru where the GDP growth has been very relevant in the last twenty years (Figueroa, A., 2008). Additionally, in the scenery of developing countries, globally, it has been calculated that there is a 9% increase in hourly earnings for one extra year of schooling (Psacharopoulos, G. et al., 2018).

The recent pandemic crisis had shown that only those with jobs adopted to the current digital economy could introduce massively home working; in Latin America, lower-income economies have a lower share of jobs that can be done at home (Dingel, J. I. et al., 2020). Also, at a micro-level, workers from developing regions and lower wages had a more challenging time continuing to work during the pandemic, increasing overall economic vulnerability and worsening inequality in lower-income households (López-Calva, L.F., 2020).

In a new Digital Economy, developing countries must aim to become not only countries of manufacturing outsourcing but also move into high skilled services with customer call centres, data entry facilities and higher-skilled professional jobs ranging from engineering to artificial intelligence (Lieberman, J. I., 2004). It is therefore relevant for developing economies, not only to ensure economic growth but also to build a more resilient and inclusive economy, focusing on how Digital Education is preparing future adults of the next generation to acquire the required Digital Competences to enter the labour market prepared with sufficient ICT skills.

More developed economies are focusing on the learning process at schools and on lifelong learning opportunities at university or on how to upscale the current workforce (Beblavý et al., 2019). At the same time, systematic research has been developed in order to provide trend analysis and country comparisons of their digital performance (Foley et al., 2018).

However, there is lack of information on the overall deployment and evolution of Digital Education in developing countries and this research tries to contribute to close this knowledge gap. Inspired by the mentioned studies and to determine the state of readiness of a particular country in terms of Digital Education acquisition at early stages of schooling, a Digital Education Index for Developing Countries (DEIFDC) has been defined. For this characterization, three specific levers relevant at low levels of education have been considered, mainly for primary schools where the impact has demonstrated to be higher (Heckman, 2007).

The selection and weighting of levers and variables have been carried out based on the detailed overview of supporting literature, mainly professional journals, expert think-pieces, case studies, interviews, systematic reviews, comparative studies and policy statements.

In order to apply the DEIFDC to the specific Peru case, detailed research of the education system has been conducted, as well as a revision of the different policies and programs that have been undertaken on Digital Education in Peru in the past 20 years that are directly impacting the variables that compose the index. In this sense, the DEIFDC will assess the current deployment of Digital Education in the midst of the Covid-19 pandemic, but it will not measure the social, political or cultural implications that might be affecting the index construction.

## 2. Methodology

### 2.1. Relevance of Digital Education

In the context of a new Digital Era, Digital Education is considered as a key factor to link schooling and the future of a Digital Society. Investments in education are critical for developing the human capital that will end extreme poverty (United Nations Development Program, 2019) and priority should be given to the lower levels of education in countries that have not yet achieved universal primary education (Psacharopoulos, G. et al., 2018). Although there are several definitions for Digital Education that can be applied depending on the stage and purpose of education, i.e., early childhood, K-12, professional, university and life-long learning, for the purpose of this research, Digital Education has been defined as the process of teaching and learning in schools that is facilitated by Digital Technologies.

Digital Technologies have been progressively introduced in most Education systems, even if traditional textbooks and chalk and board were also used. Nowadays, and due to the workarounds originated due to the school closures during the pandemic, many education world leaders agree that technology is no longer a supplementary tool and that it should be fully integrated into all Education Systems (Gianini, S., 2020).

Digital Education is striking as it prepares children to acquire the digital competencies needed in a 21st century workforce like digital literacy and computational thinking (World Economic Forum, 2020). Nevertheless, these skills cannot be considered isolated, and it is necessary to use a holistic approach in which the new ways of teaching and learning will also help children to acquire a series of soft skills that have been described in several frameworks, such as the four C's (Ruhl, J., 2015): critical thinking, creativity, communication and collaboration, the ABCs, adapt, be resilient and communicate (Wilson-Body, P. 2020) or the four Pillars of Education: learn to know, learn to do, learn to live and learn to be (Unesco, 2015). Recent studies (Ganimian, A.J. et al., 2020) suggest four different ways to realise the potential of education technology to accelerate student learning and focus on potential uses of technology that play to its comparative advantages: scaling up quality instruction, facilitating differentiated instruction, expanding opportunities to practice and increasing learner engagement through videos and games.

For the purpose of this research and focusing on primary schools, Digital Education has been approached into two different areas depending on their potential use, individual and collective education technologies as they will help the children to develop the required 21st-century competences. Individual learning tools are mainly based on the usage of educational resources on computers, tablets or mobile phones to speed up the learning process by giving each student access to different content available from the Internet or previously downloaded and made available offline. This way of working is differential for three reasons:

- a) Knowledge boundaries: It extends the boundaries of knowledge of the traditional textbooks, especially if the children are able to connect to the internet and explore further than what it is written in the books just with a device, this process can be thought to be similar to have access to an infinite

library where thousands of books are available, and children are capable of conducting their own research (Mitra, S., 2014).

- b) Adaptive learning: It introduces the concept of learning personalization and the ability of the educational resources to adapt to the current capacities and abilities depending on the student level, its achievements and misconceptions (Luckin, R. et al., 2016).
- c) Evaluation and assessment: It facilitates evaluation and assessment as different types of tests and questionnaires can be applied to verify students' levels at different stages of the learning process, at the same time as it simplifies the individual certification or warranty of proficiency in certain subjects or matters than can be used to access higher education or specialized jobs (Beblavý et al., 2019).

The collective learning digital tools bring a new way of working soft skills that allow teachers to introduce complementary forms of interaction among students. It changes the way of interaction in a classroom from a teacher-centred approach to a student-centred approach (Ruhl, J., 2018). These tools can be interactive white-boards (IWB) (Lopez, O.S., 2010) or projectors, but also more advanced systems such as Virtual Learning Environments (VLE) or Learning Management Systems (LMS) deployed either locally or connected to the Internet (Light, D., 2016):

- Teamwork and collaboration: The students can be grouped in smaller clusters to develop different subjects, research together or complete tasks that involved thinking out of the ordinary (Scheuer, O. et al., 2010).
- Peer evaluation: The software deployed in tablets or computers allows the students to assess their peers' work and help them create a collaborative environment where everyone learns from both producing and revising the work of others.
- Gamification: It helps to motivate the students with the creation of avatars and game-related content that can be used to deeply study a specific matter; the children will get higher scores depending on how they dominate the subjects (Freitas, S., 2011).

## **2.2. Research model**

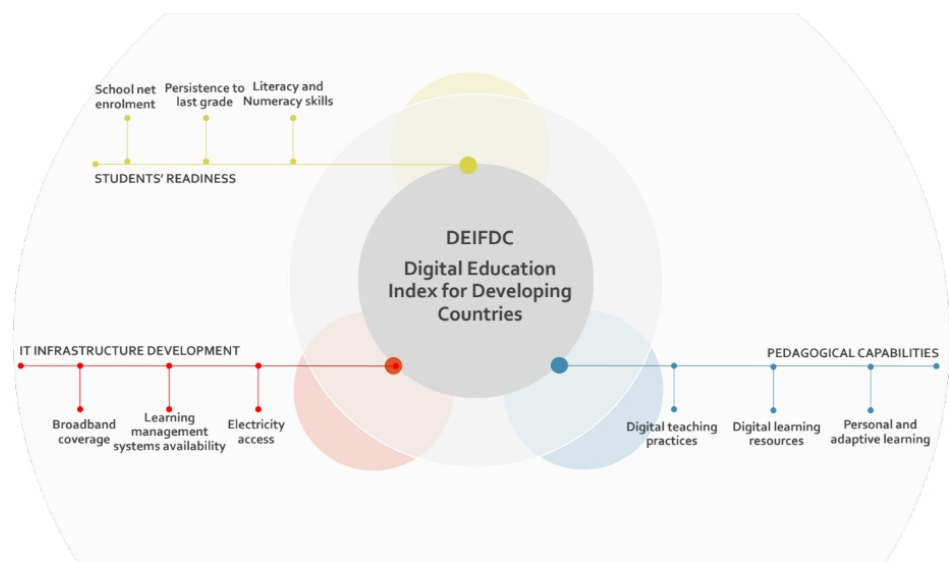
The Digital Education Index for Developing Countries (DEIFDC) is a geometric mean of nine different variables that have been grouped into levers and assigned a different weight based on the implications to deploy Digital Education in primary schools of Developing Countries. The index composition is based on the most relevant categories considered to assess Digital Education readiness: Students' Readiness, IT Infrastructure Development and Pedagogical Capabilities. The literature reviewed suggests that each of these levers provide relevant insight into a particular aspect of Digital Education. The justification of each lever and its corresponding variables and assigned weights will be described in the following subsections.

### *Students' readiness*



One of the main challenges to apply Digital Education in developing countries is that enrolment (weight: 30%) in certain areas is still a challenge; without school attendance and continuous guidance, the benefits of introducing 21st-century skills in primary schools can be reduced. It is also indispensable that children stay in primary school and keep on studying until last grade (weight: 30%), this is beneficial in terms of individuals but also in terms of society as additional years of schooling have proved to be central for employment, poverty reduction, economic growth and social cohesion.

At the same time, evidence on the importance of early environments on a spectrum of health, labour market, and behavioural outcomes suggests that focus must be put at early education stages (Heckman, 2007) rather than on secondary or lifelong learning opportunities.



**Figure 1.** Digital Education Index for Developing Countries Schema. Source: Authors' elaboration.

Among the benefits of introducing Digital Education at an early stage is the reduction of learning poverty (World Bank, 2019) that is mainly measured by the students' capacity to read and write and solve mathematics problems related to daily life (40%). Although several countries have been measuring education's impact, the most extended analysis is based on PISA, the Program for International Student Assessment, developed by the OECD to measure 15-year-olds' ability to use their reading, mathematics and science knowledge and skills to meet real-life challenges (Ministerio de Educación de la República del Perú, 2021).

Early Digital Education brings, as a result, the interest of students in pursuing advanced STEM education, the new professions of the future (World Economic Forum, 2020) require the professional labour to adapt to reality in the new Digital Era. This means that children in primary schools must acquire the basics to be ready to pursue this specific knowledge but not that every student must be a data analyst or an engineer.

### *IT Infrastructure Development*

The adequate deployment of infrastructure is critical to ensure that children can receive the initial instruction required in developing countries schools, as family support that is usually the first step of Digital Education introduction in developed countries, cannot be ensured. Electricity access (weight: 40%) has been given the most relevant load as it is crucial that the ICT equipment (computers, tablets, routers or projectors) is appropriately charged. When no standard electricity access is possible due to geographic or economic conditions, there are other ways to ensure batteries can last during the school day, and several deployments have been proved successful such as solar panels or solar chargers for specific equipment; however, normally, their capacity is conditioned to weather circumstances and the quality of the equipment provided. Other renewable energy technologies like wind turbines, small-scale hydroelectric projects and other forms of self-sufficient energy can provide rural communities in the developing world with the electricity they need to power schools (Solar Energy International, 2018). Even if educational resources can be made available and previously uploaded, internet access (weight: 30%) ensures that broad knowledge and content can be used in the classrooms (International Telecommunication Union, 2013). This is particularly relevant in contexts where advanced individual or collective learning tools are being introduced, such as adaptive learning and gamification (Internet Society, 2017).

Although it seems Digital Education deployments should start with the delivery of a laptop or tablet to children in school for individual use, the standard approach that has been carried out in more advanced Education Systems is through the usage of Interactive White Boards, Learning Management Systems and projectors in the classroom (weight: 30%). This introduction allows the Primary Education teachers to expose content and familiarise the children with Digital Education. Particularly, educators can use IWBs to empower students with 21st-century skills and create exciting new learning opportunities for promoting STEM education, problem-solving, critical thinking, and collaboration skills among their students (Yinghui, S., 2012).

### *Pedagogical Capabilities*

Within this section, the variable with the greatest importance is the training of teachers (weight: 40%), as it is considered critical to the success of introducing Digital Education in the schools (Panagiotis, K. et al., 2015). In this sense, it is not only necessary to teach them how to use the new ICT tools but also to provide pedagogical support and continuous professional development to ensure they can apply innovative methodologies in the school and work on the competencies that Digital Education facilitates as it has been proposed by several frameworks.

The second variable in terms of importance is the availability of adequate content (weight: 35%). Advanced digital content has traditionally been exploited by EdTech companies that made the content available through web access, applications and different types of licences. However, new regulations on Open Educational Resources (Unesco, 2019) have made plenty of digital content available, especially after the Covid-19 crisis and to students and teachers with an internet connection. Although this is a progression that can make a difference in developing countries, it is necessary to adapt it to each environment's specific curricula (Trucano M., 2010), local languages,

contexts without an internet connection or specific devices different from laptops like mobile phones.

Electronic devices' penetration per student (weight: 25%) has been considered of less relative relevance as it has been proven that deployment of ICT labs and equipment sharing is also a good practice to introduce Digital Education in the education process.

However, it is essential to ensure unique login to identify students' sessions and relevant to apply some of the advantages that Digital Education provides in terms of personalisation (Luckin, R., 2016), gaming, evaluation and certification.

*Procedure*

The equations defined to calculate the DEIFDC are as follows, where each variable will be given a 0-1 scale:

$$L_1 = 0.3 V_{1.1} + 0.3 V_{1.2} + 0.4 V_{1.3}$$

$$L_2 = 0.4 V_{2.1} + 0.3 V_{2.2} + 0.3 V_{2.3}$$

$$L_3 = 0.4 V_{3.1} + 0.35 V_{3.2} + 0.25 V_{3.3}$$

This will result in an index calculated on the geometric mean of the three different levers previously constructed:

$$DEIFDC = \sqrt[3]{L_1 \cdot L_2 \cdot L_3}$$

Depending on the Index result, the different countries understudy will be grouped according to one of the following categories (Table 1).

**Table 1.** DEIFDC Weight variables. Source: Author’s elaboration.

Lever/variable	Assigned weight
Students’ Readiness ( $L_1$ )	
School net enrolment	30%
Persistence to last grade	30%
Literacy and Numeracy skills	40%
IT Infrastructure Deployment ( $L_2$ )	
Electricity access	40%
Broadband coverage	30%
LMS availability	30%
Pedagogical Capabilities ( $L_3$ )	
Digitally teaching practices	40%
Digital learning resources	35%
Personal and adaptive learning	25%

**Table 2.** DEIFDC and Levers Distribution. Source: Author’s elaboration.

A. Excellent	0.9-1
B. Good	0.8-0.9
C. Adequate	0.6-0.8
D. Insufficient	0-0.6

**2.3. Research context**

Peru is located in South America, bordering Bolivia, Chile, Ecuador, Colombia, Brasil and the South Pacific Ocean. It has a vast diversity, both cultural and geographical, that are

often linked, drawing significant national differences between the coastal areas, the Amazonian regions and the Andean mountains. Although Spanish is the most common official language, there are other 47 indigenous languages, mainly Quechua and Aymara, that conform an important diversity in terms of cultural differences (Ministerio de Educación de la República del Perú, 2013).

Peru's economy has been one of the most prominent performers in Latin America in the last 25 years averaging 5.3 per cent growth since 2001, besides, its economy is one of the largest in Latin America and the Caribbean. However, there are great differences between the coastline regions and the Andean and Amazonian ones; for example, the Lima area accounts for one-third of Peru's population and one half of its GDP (World Bank Group, 2017).

Peru ranks 82 in the Human Development Index with an IDH of 0,759 considered within the high group of Human Development (UNDP, 2019). However, the indicators of Peru in social and infrastructure metrics show that Peru is lagging behind its structural peers in almost all indicators such as electricity, sanitation, water, access to mobile phones and internet users, paved roads, stunting, secondary school degrees, social insurance and pensions (World Bank Group, 2017). This particularly affects 7.6 million indigenous people, around a quarter of Peru's 32 million population, where the higher poverty ratios are found. The higher poverty incidence among indigenous people is often driven by the fact that they live in rural areas rather than by their ethnicity (World Bank Group, 2017).

The main economic sectors in Peru are services, construction and mining. It is a wealthy country in terms of natural resources such as gold, silver and copper that drive substantial foreign investments; however, according to the World Bank, the lack of investments in innovation and more productive digital technologies is constraining growth: low productivity, slow technology adoption, lack of export diversification that are all closely related, describing an equilibrium of weak labour demand for productive, well-paid jobs. In this aspect, the impact of Digital Education will be profoundly analysed at early stages of schooling and the conformation of a digital high productive and high waged labour.

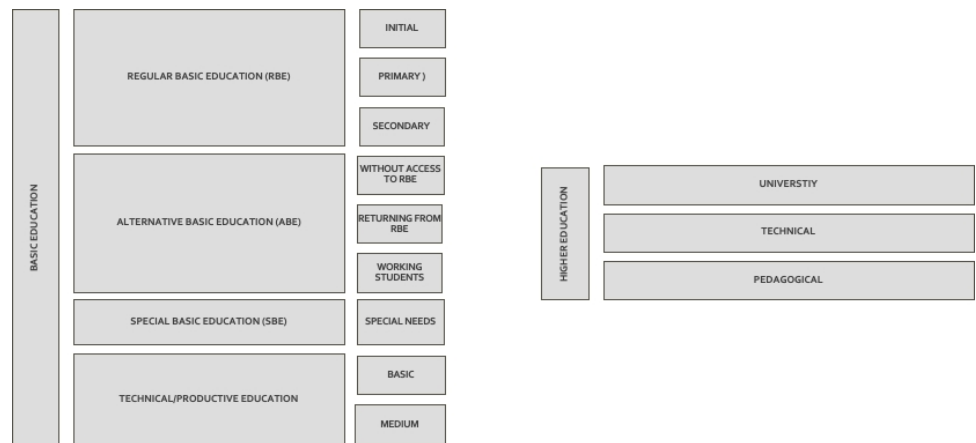
The key areas prioritised for action to ensure sustainable development are closely interrelated with the raising of human capital (World Bank, 2017) and also involve the improvement of connecting infrastructure and public services, government coordination, law enforcement and reduction of environmental risks, among others.

According to the INEI, in 2018 there were 567,347 teachers, 113,069 schools and 8,815,800 students in the Peruvian Education System organized following the procedures of the General Education Law (Ministerio de Educación de la República del Perú, 2003). The education system has been structured in stages, levels, modalities, cycles and programs, these terms will be explicitly referred within the Peruvian context:

- The stages are the progressive periods in which the educational system is structured according to each student's learning needs.
- The levels are the periods within the educational stages.

- The modalities are educational alternatives organised according to the specific characteristics of students
- The cycles are developed based on learning achievements.
- The programs are sets of educational actions developed to meet specific demands

As we can see in figure 2, the Peruvian Educational System comprises the following two stages: (a) Basic Education, as a means to acquire fundamental competencies, promote the students’ integral development and the development of capacities, knowledge, attitudes, and values to act and live in society adequately. It also attends from an inclusive point of view, children and adults with special educational needs or learning difficulties. (b) Higher Education, which is focused on specialisation and the acquisition of specific competences like high-level professional skills in accordance with the la-bour skills demanded by society.



**Figure 2.** Peruvian Education System. Source: Author’s elaboration with data from the General Education Law (Ministerio de Educación de la República del Perú, 2003).

LEVEL	INITIAL		PRIMARY				SECONDARY								
CYCLE	I		II		III	IV	V	VI		VII					
GRADE	0-2 (years)		3-5 (years)		1st	2nd	3rd	4th	5th	6th	1st	2nd	3rd	4th	5th

**Figure 3.** Basic Regular Education. Source: Author’s elaboration with data from the Basic Education Curriculum (2016)

As we can see in figure 3, Regular Basic Education is divided into seven cycles that correspond to the central and more extended educational modality in Peru. It takes care of children and adolescents that adequately go through the educational process according to their physical and cognitive evolution.

For this study's purpose, only the schools within the Regular Basic Education have been considered leaving potential further research for the deployment of Digital Education in Alternative Basic Education, Special Basic Education, Technical Education and Higher Education. Additionally, special attention has been paid to the cycles that belong to primary education bearing in mind the importance of the last year of initial education compulsory in Peru to the first cycle of secondary education where the main competences acquired during Primary years are evaluated.

It is worth pointing out that the general education law considers as the main objectives of Basic Education not only the learning processes in the traditional fields of science, humanities, culture, art, physical education and sports, but also those that will allow the students to make good use and enjoyment of new technologies.

The Basic Education Curriculum (Ministerio de Education de la República del Perú, 2016) defines 29 general competences that children must have achieved by the end of the 6th grade. Specially dedicated to Digital Education are:

- Competence 22: Design and build technological solutions to solve problems, justifying the scope of the technological problem and its alternative solutions based on scientific knowledge.
- Competence 28: Proved capabilities in virtual ICT environments; it contemplates the creation of digital materials such as videos, presentations, designs, documents and the proficient usage of applications, the internet and social networks to integrate all its acquired knowledge.

The Peruvian government has progressively introduced ICT at different stages of education since 1996. Even if the first programs were deployed at a shallow scale, there has indeed been relevant knowledge acquired during the last 25 years, and that has positioned Peru as one of the countries with better digital response during the Covid-19 pandemic (Unesco, 2020). The main programs ordered by initiation date are:

- 1) Infoescuela (1996-2001): Teachers were trained in the Logo programming language and to use LEGO kits. The program was evaluated by MIT (Linares, J., 2016) and supported by Seymour Papert himself (Papert, 1993). Its deployment was remarkably reduced, and in 2001 there were only 360 active schools (Marcone, 2010).
- 2) Edured (1996-2001): It aimed to provide schools with an internet connection to improve the quality of learning and modernise high schools (Salas-Pilco et al., 2014). In 2001, there were 345 high schools implemented with internet access, but only 74 of them had the project in operation (Marcone, 2010).
- 3) Huascarán Project (2001-2007): This project tried to introduce ICT in Peruvian schools at a large scale compared to the previous projects that could be considered more like pilots. It developed a whole program that included not only the computer lab equipment and the internet access in the schools but also the training of teachers and the appointment of an ICT teacher

specialist per school (Marcone, 2004). In 2001 there were 3,000 schools equipped, but most of them were urban schools as the rural schools required antennae to provide an internet connection.

- 4) One Laptop per Child (2007-2011): The OLPC implementation is one of the most well-known deployments of the program in the world and has been largely analysed. More than 800.000 XO laptops (Rivoir, A., 2016) were either handed over to students in rural areas or as a part of a Digital Lab in a second phase due to budget restrictions. The program had a formal evaluation using randomised control from the InterAmerican Development Bank, and it was found that even though there was no improvement noticed in literacy and numeracy competences, children and their families had a positive perception of the program and increased competence in the usage of ICT tools (Santiago A. et al., 2010). Also, it was found that it had impact on cognitive skills, although much effort had to be dedicated to teacher's qualification (Cristiá, J. P. et al., 2012)
- 5) PeruEduca (2011-now): This project tries to create a community for teachers where they can access online MOOC training and certification and digital resources to use in their classrooms. It also allows them to publish in blogs and forums and create specialised groups.
- 6) Aprendo en Casa (2020-now): In 2020, during the Covid-19 crisis, all schools were closed for the whole school year, but there were several initiatives based on digital capabilities already installed that ensured that up to 93% of the students could follow on with their learning (Semáforo Escuela, 2002). The project is aimed at Basic Education (Ministerio de Educación de la República del Perú, 2020), and it is very innovative as it is not only based on access to the internet but also broadcasted by television and radio. In the short term, it has been used during the pandemic crisis, but in the long term, it will try to reduce the educative gap between urban and rural zones in Peru.
- 7) Tablet distribution and virtual/presential hybrid approach (2020-2023): The plans of the current government in order to keep on responding to the pandemic crisis in Peru consist of ensuring quality infrastructure in schools, provide access to digital tools, distribute more than 1 million tablets (Ministerio de Educación de la República del Perú, 2020) and increase internet coverage in rural regions. There will be three ways to provide lectures, and it would be possible to combine virtual and presential lessons in schools and a complete virtual education model depending on the necessity and region. With an increase of 2.83% in the public budget allocated to Education (Ministerio de Economía y Finanzas de la República del Perú, 2020), it will be possible to prioritize essential literacy and numeracy, emotional aspects and digital competences (Fundación Santillana, 2020). The tablets acquired count with more than 35 applications and 3,000 educational resources that will be used by children in the last cycle of Primary Education and Secondary Education of rural areas and will be delivered to 90,000 teachers (Ministerio de Educación de la República del Perú, 2020). In a zone with internet coverage, the tablet will have a data chip to provide internet access for both children and teachers, and if there is no internet coverage, the content will be uploaded previously in the tablet so it can be available offline. Also, a solar



charger will be provided to be used in those areas with no access to current electricity. It has also been considered of great importance that the teachers in the program count with specific training on digital literacy and competences with preuploaded training resources in the tablets (Ministerio de Economía y Finanzas de la República del Perú, 2020).

Peru has been having an outstanding performance in terms of GDP growth, the best of the region during the last two decades (World Bank Group, 2017). This growth helped reduce poverty for each percentage point increase in GDP growth and poverty fell by 1.4 percentage points. Thus, from 2004 until 2015, 9.3 million Peruvians escaped poverty, moderate poverty fell by more than half, from 58 to 22 per cent, and extreme poverty fell from 16 to 4 per cent. In Peru's case, GDP growth has been based on natural resources and has attracted foreign investments in mining and enabled growth based on fast capital accumulation, although with few gains in productivity and negligible export diversification (World Bank Group, 2017). This GDP growth is based on the measurement of the monetary value of all final goods produced in an economy (Brynjolfsson, E. et al., 2019), but it does not include digital offerings as free digital goods are consumed at no cost, which is relevant as it increases the gap related to the Digital Economy that has not been taken into account.

Overall, Peru has a very slow digital development and ranks below its regional peers on digitisation (BBVA, 2017; Sethi, A. et al., 2020), largely because it falls short in infrastructure as it has low internet usage compared to other Latin American countries in terms of private and public sectors and personal use. Only 45% of Peruvians use the internet, but in urban areas, the rate is 54%, whereas, in rural areas, it is only 14%. Geographically, there is also a significant difference: over 63% of the population in Lima's province use the internet, whereas, in Cajamarca, Huancavelica and Amazonas, this rate is around 20%. Young people and those with a medium-to-high education level use the internet most, having a considerable impact on qualified job opportunities and participation in the digital economy. The internet is mainly used for communicating, obtaining information, and entertainment, but the usage for interaction with the public sector, electronic banking, buy or sell product and services or training is residual. The evolution has been very positive with recent analysis in 2019 situating on 57,1% the percentage of the Peruvian population that uses the internet, an increase of 10 points in only two years (Instituto Nacional de Estadística e Informática, 2019).

76% of private companies use the internet, nevertheless, only around one-third of them have all their employees using it due to the internet connection speed. Companies in Peru are too slow in the adoption of new technologies. Only 7 per cent of firms have licensed technology from abroad, compared to 14 per cent in the Latin-American region as a whole. They also lag in the adoption of new digital technologies; for instance, less than 20 per cent of formal sector retail firms sell their products online, despite the significant opportunities to enhance their scale and productivity through online trade. This is among the lowest online shares for retail firms in Latin America as in Mexico, Colombia, and Chile, between 50 to 80 per cent of all sector retailers offer online sales (World Bank Group, 2017). There has been progress in government digitisation in Peru over recent years thanks to the effort of the SeGD<sub>i</sub> (Secretaría de Gobierno Digital) that is in charge of developing internet policies, national plans, standards, guidelines and strategies in e-government and IT matters. However,

although it has developed several applications and web services, the government's online services and their perceived benefits still lag its peers in Latin America.

### **3. Results**

#### **3.1. Data Analysis**

The existing data suitable for constructing the DEIFDC was obtained from reputable available national and international sources through desk research. Data sources include global databases like the UIS Unesco Database and the World Development Indicators from the World Bank, as well as local Peruvian sources like Semáforo Escuela and standard PISA (Programme for International Student Assessment evaluations) results of 2018. The use of international databases will be useful to build a base for comparison among other developing countries where the DEIFDC will be applied. However, we still encounter other limitations like the availability of annual data to determine future evolution and the monitorisation of SDG 4 targets at a sufficient disaggregation level that will allow deep dive into a particular social (gender, castes, disabled) or geographic (rural/ urban, coastal/mountain) group.

#### **3.2. DEIFDC Scores**

The analysis and application of the DEIFDC came with relevant insights on the development of Digital Education in Peru. Overall, with a result of 0,711 is situated within the countries with Good Digital Education deployment. In terms of Students' Readiness (figure 4), the Peruvian context has considerable room for improvement. Even if net enrolment and persistence to the last grade of primary schools are reaching levels of high-income countries, 96.91% and 93.09%, respectively, the PISA evaluation levels are still deficient (42.46%), almost matching the levels of learning poverty, especially in mathematics (39.66%). This factor is very relevant because it demonstrates that even if all efforts are made in a good direction, the instruments that are put in place also need to focus on the basic literacy and mathematics competencies.

This lack of basic competences then translates into a subsequent variable resulting in only 31.70% of students applying on STEM superior education that will lead to scarce fulfilment of digital job positions. This lever brings an important point related to Digital Education and the fact that the introduction of ICT in the education systems does not help improve the learning process's efficiency, and it only aims to acquire complementary competences like research, organisation, problem-solving, collaboration, teamwork and project development (Macone S., 2010).

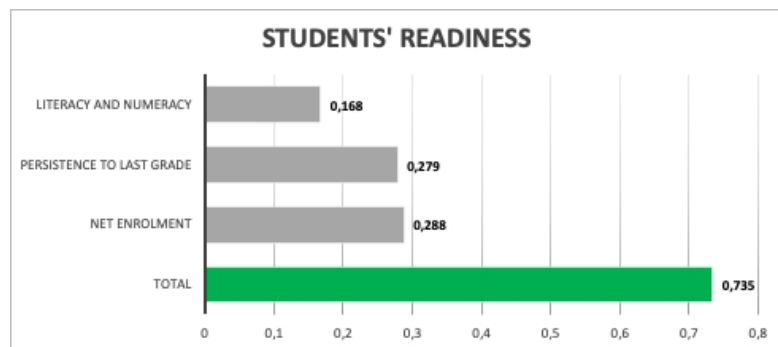
Further research will need to determine the current effects of Digital Education on future evaluations of basic competences, so far increased levels of school attendance, decrease in dropout rates, students and teachers producing and sharing information, improvements in educational management and teachers' training have been demonstrated but impacts behind in the improvement of reading, writing and math skills are yet to be analysed (Cardim, J. et al., 2021).

As we can see in figure 5, in terms of infrastructure, the Peruvian government has made plenty of effort to ensure schools count with electricity by standard means or with other renewable energy sources reaching almost 79.93% of the schools. However,

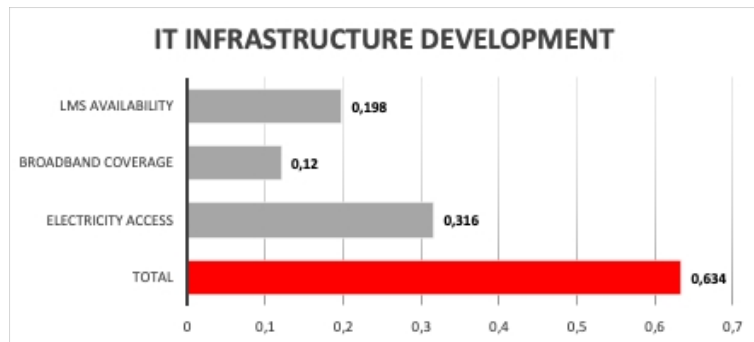
only 40.77% of schools had an internet connection, making it challenging to introduce online learning individual and collective tools. Even though there is no data available on the deployment of LMS, IWB or projectors in schools, during 2020, at least 66.9% of teachers were using *Aprendo en Casa*, which is a very high penetration and demonstrates an outstanding response throughout the school closure originated during the school year. With a total of 0,634 the School Infrastructure Development is adequate, however, additional effort needs to be made in terms of inter-net connection and usage of LMS, IWB and projectors to ensure the basic infrastructure is deployed both in rural and urban environments.

As we can see in figure 6, the pedagogical capabilities lever represents the highest score of the three levers that compose the DEIFDC. Teachers in Peru are receiving Digital Education instruction both in their initial capacitation programs and as part of their lifelong learning to enrich their curricula. In this sense, the PeruEduca portal is a centrepiece to ensure the acquisition of these abilities.

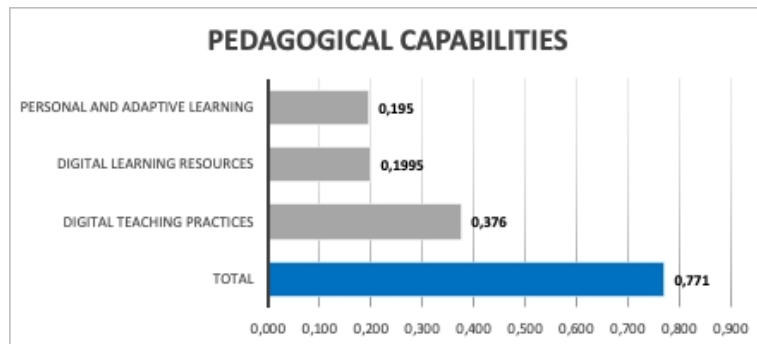
The availability of digital learning resources has also boosted during the pandemic crisis when it was necessary to reach children in their homes; in this sense, it is essential to consider that most of these resources are online and mainly in Spanish, leaving behind those rural areas where the mother tongue is an indigenous language, and the internet connection is not a reality. In terms of penetration, the last data available from the UIS database regarding the number of schools with access to computers for pedagogical purposes was 78.31%, almost 80%. However, this data does not consider the latest distribution of tablets started by the Peruvian government (Ministerio de Educación de la República del Perú, 2020).



**Figure 4.** Students' Readiness. Source: Authors' elaboration with data from World Development Indicators (World Bank) and PISA 2018.



**Figure 5.** IT Infrastructure Development. Source: Authors' elaboration with data from UIS Unesco Database and Semáforo Escuela.



**Figure 6.** Pedagogical Capabilities. Source: Authors' elaboration with data from UIS Unesco Database and Semáforo Escuela

#### 4. Conclusion

Success in the Digital Age requires Digital Skills (Internet Society, 2017). As primary school children will enter the labour market in ten years' time, they will need to have acquired the basic competences of Digital Literacy: use of computers and digital equipment, ability to use online applications, find and qualify online information and make use of it in daily life. Building these skills is crucial for developing countries and should be included in the curricula and assessed in the same manner as other basic competences like reading, writing and mathematics.

In Peru, the composition of the labour market needs to upgrade to be able to respond to the demands of the new digital economy. The existing digital divide and the lack of infrastructure, especially in terms of internet connection in rural areas, is causing that developing countries lag behind in digital dividends. This situation makes them incapable of benefiting from the broader development benefits of using digital technologies (World Bank, 2016) that go beyond the traditional sectors that have been responsible for GDP growth in the last twenty years.

Several programs have tried to integrate Digital Education into the learning process by introducing different components in a linked way at different stages of education, and digital competences have been included as part of the Peruvian

national curriculum. However, still plenty of effort needs to be put in place in terms of education policies to ensure all variables affecting the three different levers of the DEIFDC work in a coordinated manner.

In the application of the DEIFDC for the Peruvian case, the results show good results on Pedagogical Capabilities and Students' Readiness but only adequate IT Infrastructure Development. The Covid-19 response has been a major boost in terms of upgrading the usage of digital educational resources and digitally train the teachers in order to be able to keep up with the lessons during the school closure. However, important differences are still very relevant in terms of rural and geographical development, which greatly affect indigenous people, due to some factors such as their mother tongue but also due to the locations where their homes are based, normally rural, rather than by their ethnicity.

The current data available from several studies that follow up the state of digital readiness of the labour market in Peru show that currently, the country has tremendous room for improvement in terms of digitalisation of the personal, enterprise and government processes. As a result, the GDP growth will flatly grow during the following years if no adequate digital development takes place.

Proposed further research will need to explore both the evolution of DEIFDC at different periods of time, its disaggregation based on gender (male-female), social origin (indigenous children, disability status and conflict-affected) or detailed geographic distribution (rural-urban, coastal-Andean-Amazonian), its possible application in higher education (secondary, technical and university) and its impact on the country's composition of the digital workforce, GDP growth, overseas attractiveness and index of digitalisation, as well as the comparison with other countries of similar economic development.

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## Guidelines for authors

### Checklist for submit manuscript

As part of the submission process, authors are required to check that their submission meets all of the elements shown below. Submissions that do not comply with these guidelines will be returned to the authors.

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- In the User Profile (Identity section) the surnames have been included in a standardised form.
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- In the User Profile (Contact section), the author's full professional address has been included under Postal address.
- All the authors of the article have an ORCID identifier.
- The title of the article is included in Spanish, Portuguese and English (max. 20 words).
- An abstract of the article is included in Spanish, Portuguese and English. In a single paragraph and without headings (min/max: 200-230 words).
- Five keywords in Spanish, Portuguese and English are included. The ERIC Thesaurus has been used for their selection.
- The text includes the other elements of the structure of an article: introduction-state of the art, method, results and conclusion-discussion.
- In-text citations and references strictly follow APA standards. The DOI has been included for all references with a DOI.
- References include all references cited in the text and only those cited in the text.
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- The text does not contain the names of the authors, nor any other identifying information.
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The manuscripts must be unpublished, not in the process of publication or evaluation by other journals.

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The author's name must also be removed in the word processor from the «Properties» of the document (File>Properties menu).

### Languages

Articles may be written in Spanish or Portuguese. All articles accepted for publication will have an English translation.

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- Identity: Surname (The academic signature -first name and surname- must be standardised in accordance with international conventions to facilitate identification in the main databases. FECYT document).
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Articles should be written in accordance with the APA Publication Manual (American Psychological Association; 7th edition).

### Article structure

All texts should include the following elements:

1. **Title:** should be informative, clear and direct. It should not contain more than 20 words (maximum 2 lines - 100 characters). It should be presented in Spanish (or Portuguese) and English.

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6. **Results:** rigorous reporting of the analysis of the evidence found should be presented. The tables, graphs or figures must be referenced in the text and the most significant results must be presented without redundancy.
7. **Conclusion-Discussion:** this should include a summary of the most significant findings and establish relations of the study with other theories or previous research, without introducing information already present in previous sections. The implications of the research, its limitations and a prospective for future studies should be presented. Claims not expressly supported by evidence from the research conducted should be avoided.

### References and citations

Bibliographical citations in the text will appear with the author's surname and year of publication (both in parentheses and separated by a comma). If the author's surname is part of the narrative, only the year is placed in parentheses. To separate authors in the text, as a general rule, quotations should be adapted to Spanish, using "and" instead of "and" or the "&" sign.

Example: Mateos (2001) compared studies carried out by... / ...in a recent study on new technologies in education (Mateos, 2001)... / In 2001, Mateos carried out a study on...

In the case of several authors, they are separated by a comma, the last author is separated by an "and". In the case of two authors, both are always cited. When the work has more than two and less than six authors, all are cited the first time, in the following citations, only the surname of the first author followed by "et al." and the year, unless there is another citation whose abbreviation results in the same way and from the same year, in which case the complete citation will be given. For more than six authors, the first author is cited followed by "et al." and in case of confusion with other references, the subsequent authors are added until they are clearly differentiated.

Example: Morales and Vallejo (1998) found... / Almeida, Manzano and Morales (2000)... / In later appearances: Almeida et al. (2000).

In any case, the reference in the bibliographic list must be complete. To identify works by the same author, or authors, of the same date, the letters a, b, c are added to the year, as far as necessary, repeating the year. Authors' surnames should be in lower case (except for the first letter, which should be in upper case). When several references are cited within the same parenthesis, they are ordered alphabetically.

Verbatim quotations. Short quotations, two lines or less (40 words), may be incorporated into the text using single inverted commas to indicate them. Longer quotations are separated from the text by a space at each end and tabulated from the left margin; there is no need to use inverted commas here. In both cases the page number of the quotation is indicated. Punctuation, spelling and order must correspond exactly to the original text. Any changes made by the author should be clearly indicated (e.g. italicisation of some words for emphasis). When material is omitted from quotations it is indicated by a parenthesis (. . .). Material inserted by the author to clarify the quotation should be placed in square brackets [...]. The source of a quotation should be cited in full, author, year and page number in the text, plus a full reference in the bibliography.

Example: «in recent years there has been an increasing interest in the study of new technologies in early childhood education» (Mateos, 2001, p. 214).

Secondary quotations. Occasionally, it will be considered necessary to present an author's idea, revised in a work other than the original one in which it was published.

Example: Classical conditioning has many practical applications (Watson, 1940, cited in Lazarus, 1982) ... Or: Watson (cited in Lazarus, 1982) argues the versatility of classical conditioning applications ...

References section. Bibliography that has not been cited in the text should not be included. Due to their relevance for citation indexes and impact factor calculations, references must follow a correct citation according to the APA 6 Standard. The use of a bibliographic manager (e.g. ZOTERO) is recommended.

All citations with a DOI (Digital Object Identifier System) should always be included in the references.

#### Examples of references, according to APA standard (7th edition)

##### BOOKS

Spector, J. M. (2016). *Foundations of educational technology: Integrative approaches and interdisciplinary perspectives*. Routledge.

#### BOOK CHAPTERS

Jagannathan, S. (2021). The digital learning opportunity. En S. Jagannathan (Ed.), *Reimagining digital learning for sustainable development: How upskilling, data analytics, and educational technologies close the skills gap* (pp. 17-35). Routledge.

#### ARTICLES

Valverde-Berrocoso, J., González-Fernández, A., & Acevedo-Borrega, J. (2022). Disinformation and multiliteracy: A systematic review of the literature. *Comunicar, XXX(70)*, 97-110. <https://doi.org/10.3916/C70-2022-08>

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### ISSN

1695-288X

### Journal design and web maintenance

Jesús Valverde Berrocoso

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FECYT-291/2023  
Fecha de certificación: 14 de julio de 2016 (5ª convocatoria)  
Válido hasta: 28 de julio de 2024