www.editada.org

International Journal of Combinatorial Optimization Problems and Informatics, 14(3), Sep-Dec 2023, 117-137. ISSN: 2007-1558. https://doi.org/10.61467/2007.1558.2023.v14i3.401

Review of Genetic Algorithm to improve Students Academic Performance by applying Smart Learning

Luis Arturo Ortiz-Suarez, Yaneth Reyes-Hernández, Uriel Amado Ramírez Hernández, Joel Silos Sánchez, Luis José Gómez Pérez, Francisco Rafael Trejo-Macotela, Daniel Robles Camarillo
Universidad Politécnica de Pachuca.
E-mails: arturo.os@ar-net.com.mx

Abstract. This paper reviews the use of genetic algorithms for enhancing academic performance through Smart learning. The study reveals that the application of technology in teaching can improve students' grades. It also analyzes the implementation of cognitive training and the benefits obtained for a better comprehension of the information received by individuals. A literature review is provided to give an overview of how these issues have impacted various parts of the world. The importance of integrating novel approaches to Smart learning, such as genetic algorithms and cognitive training, to enrich pedagogical strategies is highlighted.
Keywords: Smart learning, genetic algorithm.

Article Info
Received Sep 9, 2023
Accepted Dec 11, 2023

1 Introduction

This section describes some basic aspects of Smart learning in conjunction with a genetic algorithm as they are the fundamental basis for the development of this article.

The definition of Smart learning environments can be seen as technology-supported learning environments that make adaptations and provide appropriate support with sensing and recommendation technology (e.g. guidance, feedback, tips or tools to use) in the right places at the right time, according to the individual needs of each learner, determined through analysis of their learning behaviors, their performance trajectory and the online and real-world contexts in which they find themselves, both group and social and composed of the resources they are provided with or access, download, read or elaborate (Zapata-Roz, 2023).

The development of the genetic algorithm is largely due to the researcher John Holland, who in his research developed a technique that simulated the workings of natural selection.

Genetic algorithms work on a population of individuals. Each one of them represents a possible solution to the problem to be solved. Each individual has an associated adjustment according to the goodness of fit with respect to the problem of the solution it represents (in nature, the equivalent would be a measure of the efficiency of the individual in the struggle for resources) (Gestal Pose et al., 2010).

This paper analyses the implementation of a genetic algorithm for the creation of a Smart learning system, supported by cognitive training, to help combat low school performance in educational institutions in Mexico.

2 School performance in Mexico

In Mexico, there are factors that affect students' school performance, whereby the schooling level encompasses approximately the basic levels. In the first quarter of 2023, the average schooling of the population aged 25 to 64 was 10.3 years of schooling. (INEGI, 2023). In figure 1 we can see how this statistic has changed since 2005.

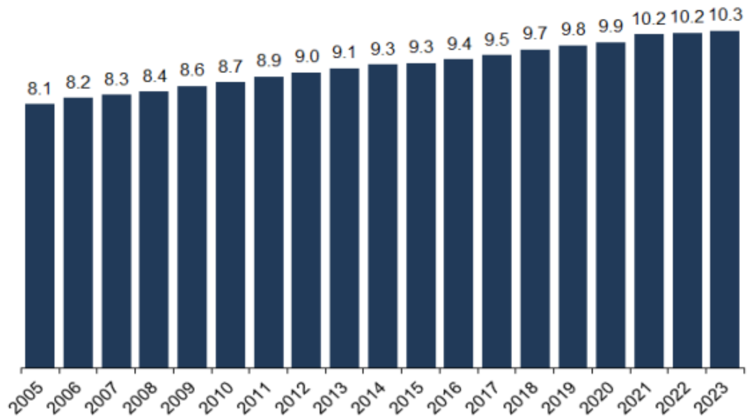

Figure 1. Average schooling of the population aged 25 to 64, 2005 to 2023. (INEGI, 2023).

According to a study conducted by the OECD (2016) underachieving in school generally increases the likelihood of dropping out of school and in the long run not finding a well-paid job, as basic knowledge and skills are lacking. Two points that stand out in the report are described below: In 2012, 55% of students in Mexico performed poorly in mathematics (OECD average: 23%), 41% in reading (OECD average: 18%), 47% in science (OECD average: 18%), and 31% in all three subjects (OECD average: 12%). Students in Mexico who attend schools with fewer mathematics-related extra-curricular activities are, on average, 14% more likely to perform poorly in mathematics than students in schools with fewer extra-curricular activities (OECD average: 8% more likely), after adjusting for students' socio-economic status.

With the development of technology in recent years, learning has been able to evolve, and with it the way students grasp information. Therefore, through the use of technology, optimal ways are sought that improve the learning obtained and that they can better develop their skills, seeking to have a broad knowledge environment in an efficient and effective manner, which allows for an increase in school performance indices.

Academic evaluation in Mexico

Academic assessments in Mexico are of great importance because they help to know the level that students have with respect to their school grade, with this we can know which schools have higher or lower academic performance of students.

In the table entitled Comparison between PISA-ENLACE we can see some of the characteristics of the assessments that have been carried out in Mexico over time.

Table 1. Comparison between PISA-ENLACE. (Virtual Learning Centre, n.d.).

	PISA	ENLACE
What is it?	It is an international comparative evaluation study promoted by the OECD (Organization for Economic Co-operation and Development) specifically designed to influence education policy in participating countries.	It is an objective, standardized test of massive and controlled application of the National Education System that is applied to public and private schools in the country.
What is its central purpose?	To provide data, reports, analyses and reports to society in general and to educational decision-makers on how well students are prepared to face the challenges of the future.	To generate a single national scale that provides comparable information on students' knowledge and skills in the subjects assessed.

What does it assess?	The ability to analyze, reason and communicate their ideas effectively and to continue learning throughout life, in three domains: reading, mathematics and science. For PISA, these domains are defined as literacy.	The knowledge and skills contained in curricula and the competencies acquired throughout their school career and the extent to which learning materials contribute to the achievement of literacy. How much the learning materials we have contribute to this educational achievement.
Who does it apply to?	Students aged between 15.3 and 16.2 years from secondary level and/or who are about to enter upper secondary education or are about to enter working life. Representative samples ranging from 4 500 to 10 000 students from a minimum of 150 schools per country are used.	In Basic Education: children from third to sixth grade of primary school and young people in the first, second and third years of secondary school. In upper secondary education: young people in the last grade of baccalaureate.
What does it consist of?	They are tests with different types of items, among which constructed-response items predominate. The content of the assessment is competency-based, i.e. in terms of the important skills and knowledge needed to respond to real-life situations. In addition, PISA collects information on student and school contextual factors including student and family characteristics, study habits, school learning conditions, school context, school organization and functioning, and available resources through student and principal questionnaires.	In basic education, ENLACE assesses students' knowledge and skills in the subjects of mathematics and science. In the subjects of Mathematics and Spanish. In addition, in order to achieve a comprehensive assessment, from 2008 onwards, a third subject is also included in each application, which is rotated each year, according to the following schedule: Science (2008), Civics and Civics and Ethics (2009), History (2010) and Geography (2011). In upper secondary education, it assesses the basic disciplinary competences in the fields of Communication (Reading Comprehension) and Mathematics.

It should be noted that both focus on obtaining data about students' knowledge in the areas of mathematics, reading and writing, and science. It also applies to certain age ranges. This provides the basis for what starting points to use their measurements, to complement them or to create new ones.

3 Smart learning

With the daily use of technology and the resulting low school performance, Smart learning systems have been chosen, which allow to know the strengths and weaknesses of the students, and from this with the use of artificial intelligence, to propose improvements so that the learning of the students increases considerably in a safe way.

Martínez Sanchez et al. (2009) defines Smart learning teaching systems as programs that carry knowledge of certain content through an individualized interactive process with the student.

This type of teaching-based system aims to obtain information from students, process it and be able to provide solutions similar to the solutions that an expert in the subject would give, with this is intended to have information quickly for decision making, which improves the academic performance of students.

Martínez Sanchez et al. (2009) mention that a Smart Learning Education System (SLES or SEAI in spanish) is composed of three fundamental modules. The Student Module stores information related to the student, through which it is determined what the student knows, and from the answer to this question it is inferred what to teach and how to teach, information represented in the Domain Module and Pedagogical Module respectively.

The importance of technology in education

Technology has become a necessity in today's world and children and adults use it on a daily basis. With the arrival of the pandemic in 2020 in Mexico, education had to migrate from school-based to virtual, a very drastic change since the new modality was very uncommon.

As we can see in Figure 2, according to a study carried out by INEGI in 2022, we can see how technology tools are within the reach of a large part of the student population aged 3 to 29.

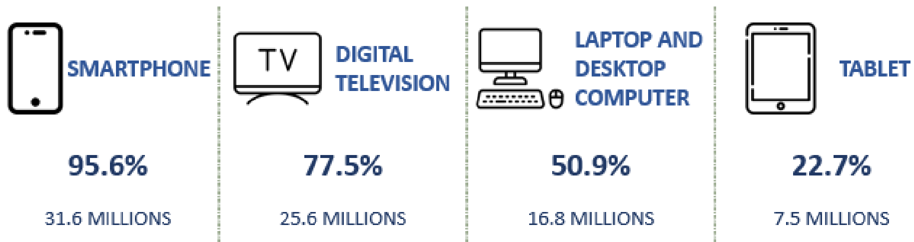

Figure 2.Technological tools used by student population.(INEGI, 2022)

This is why technological tools can be used as a channel to obtain information, and more importantly, help improve school performance by creating interactive systems that strengthen learning skills and reinforce knowledge gained in educational institutions.

Cognitive learning

We all have different characteristics and qualities that differentiate us from others. Therefore, each student has a different way of learning, as well as different skills than others. With technological progress, teaching and learning have evolved considerably, so it is important to develop the mental processes of each student to enable them to develop their skills and to understand the subjects they have more trouble learning, so that their academic performance will benefit.

According to Pulido (2018), cognitive learning is considered as a reference point, which is not based on qualifying knowledge, but focuses on increasing the capacity of mental processes, thus not seeking to evaluate the individual, on the contrary, it focuses on improving the way in which new knowledge is acquired. The mental processes are memory, language, attention and problem solving.

In Figure 3 we can see that in order to achieve cognitive learning, people's senses must be involved as well as their interaction or implications with what is happening around them, and thus achieve a response from certain areas of their brain so that these areas are strengthened.

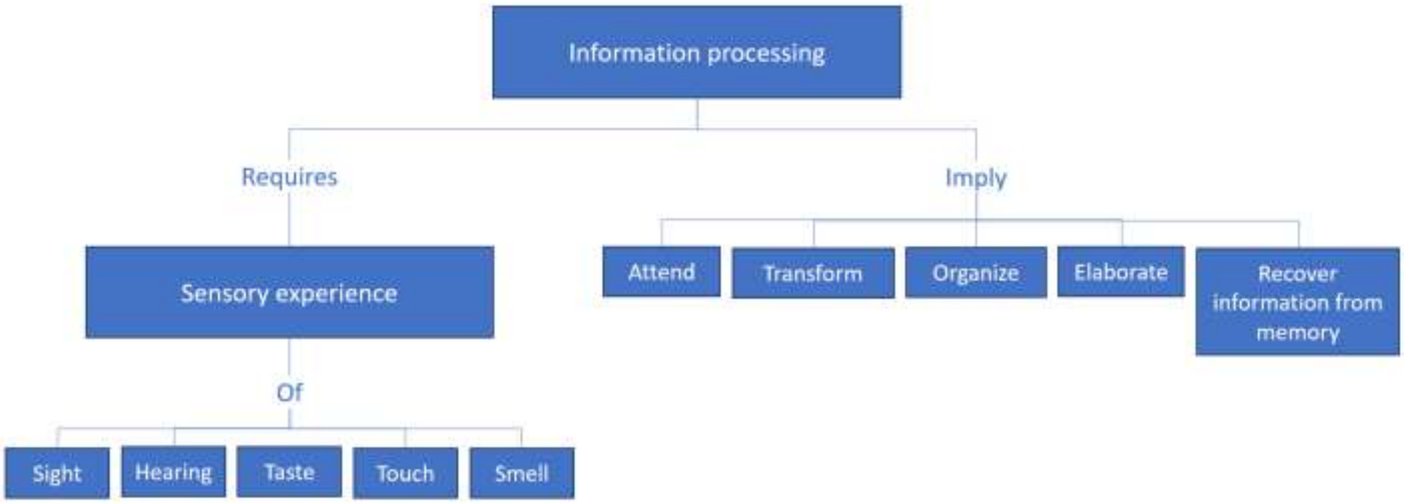

Figure 3. Behavioral responses for cognitive learning. (Pulido, 2018)

Within Smart learning, the elements of the cognitive processes involved in cognitive learning must be considered, and in this way strengthen and encourage a better response to the stimuli of students, including curricular and extracurricular activities that take place in educational institutions. These processes are:

- Perception: how information is received through the senses.
- Attention: focusing on information.
- Memory: how information is stored and retrieved.
- Thinking: how to generate ideas.
- Reasoning: using logic and knowledge to solve problems.

Smart-learning systems

Considering the definition of Smart learning that was exposed at the beginning of this article, nowadays there are information systems and applications that help to reinforce different skills and areas of knowledge.
We have also addressed the issue of cognitive learning and have seen its importance in improving brain processes, as these have a positive influence on the way we acquire and process the information around us. Applications such as cognifit in this area help to train this part of the brain.

According to Breznitz (2011) One of cognifit's main features is its Individualized Training System, which uses algorithms to learn about the user's specific characteristics, allowing the user to customize the activities to be performed in order to obtain the best possible performance during the time the application is used. A very important point is that as the user progresses in their training, the activities slowly move to a higher level of complexity which helps to maintain attention.
Using the program on a daily basis helps to improve cognitive task performance, and results can quickly be seen in people's daily life activities.

On the other hand, we have systems such as © Khan academy, a platform that offers educational resources with topics about mathematics, science, economics, programming, etc. It has multimedia resources, images and interactive activities that help to reinforce knowledge. Antequera Guerra (2013) mentions that it allows the student to work independently and the constant and effective supervision of the teacher both in class and at home.

Tapia Bernabé (2019) mentions in his research that the use of © Khan academy increased mathematics performance in CONALEP (National College of Technical Vocational Education) students. Some of the results are the following:

- Students who used "Very frequently" the © Khan Academy platform, had on average a performance of 43% in Mathematics, 4 percentage points above the average.
- Students who "Frequently" used the © Khan Academy platform had a Math’s performance of 41%, 2 percentage points above the average.
- Students who reported "Never" using the platform averaged 35%, 4 percentage points below the average.

With the analysis of these systems, it is easy to infer that Smart Learning is a powerful tool for education, however, it must evolve quickly in order to be used in a school environment.

On the other hand, we have systems such as © Khan academy, a platform that offers educational resources with topics about mathematics, science, economics, programming, etc. It has multimedia resources, images and interactive activities that help with the reinforcement of knowledge. It mentions that it allows the student's autonomous work and the constant and effective supervision of the teacher both in class and at home.

4 Genetic algorithms

According to Kuri Morales & Galaviz (2002), there are 3 historical references related to the beginnings of the genetic algorithm. The first one is the evolutionary strategies introduced by Rechenberg in 1965, these are an optimization method based on the natural evolutionary process and are designed to find solutions to problems that have multiple variables.

The second is evolutionary programming, which emerged in 1960 and was developed by Fogel, Owens and Walsh. This is a method that applies evolutionary processes to programmed structures that undergo random changes to find solutions in the design space, all this by means of transition diagrams with random changes applied to finite state machines.

And finally, the genetic algorithms developed by John Holland and his team at the University of Michigan are a class of algorithms inspired by natural evolution that resulted in optimization methods and were the result of trying to abstract the essential features of the evolutionary process.

All three approaches are inspired by natural evolution, although genetic algorithms focus on the process of adaptation and how to import it into computer systems.

Basis of the genetic algorithm

According to Kuri Morales & Galaviz (2002) the algorithm will receive as input a population of chromosomes and from this it will generate new populations, where some chromosomes will disappear while others, with better aptitudes will remain as best possible solutions, appear more frequently until a satisfactory one is found or until some other termination condition is met.

The genetic algorithm works basically with 3 iterative steps which are as follows:

- The domain elements are located to what is called phenotype.
- The problem is encoded in the form of what a genetic code would look like, which is called genotype.
- The elements of the genotype are manipulated by crossing them with other values to find more efficient combinations; these genotypes become the basis for the next generation.

This process is repeated until the best adapted individual, or in our case a satisfactory solution, is found.

Heuristic genetic algorithm

Gestal Pose et al. (2010) indicate that in order to reach the solution to a problem, we start from an initial set of individuals, called population, generated randomly. Each of these individuals represents a possible solution to the problem. It is important to mention that the genetic algorithm is a heuristic search, since by means of strategies it allows a series of optimal alternatives to be obtained randomly, since, as mentioned, it evaluates various "paths" before presenting a solution that is not necessarily unique and exact.

Selection methods

Estévez Valencia (1997) mentions that the selection mechanism allows orienting the search to the most promising points with the greatest adaptation observed so far.

Analyzing the problem will provide us with the necessary tools to be able to choose an adequate selection method and thus obtain optimum results. Estévez Valencia mentions that there are several selection methods and they are the following:

- Proportional.

- Roulette method.
- By ranking.
- By tournament.
- Crossover.

Considerations

Genetic algorithms help greatly in the optimization of problem solving, in fact, it is their main function, however, it must be taken into account that they cannot be applied in all areas or problems, it must be taken into account that the problem has certain characteristics so that it can be solved by this method (Arranz de la Peña & Parra Truyol, 2007), and they are listed below:

- Its search space must be delimited within a certain range.
- It must be possible to define a fitness function that indicates how good or bad a certain answer is.
- The solutions must be encoded in a way that is relatively easy to implement in the computer.

5 Genetic algorithm in smart learning

As mentioned, genetic algorithms using the principle of evolution seek to solve problems through strategies that allow finding different solutions and choosing one of them, with which it is intended to visualize how this algorithm can help in Smart learning by providing measures that can be taken so that students have better learning and that the quality of teaching is optimal.

In this research we found several articles related to Smart learning, the technology they use and the various methods or algorithms they develop. The following table lists the most relevant ones:

Table 1. Related articles.

Related Articles	
Computerized educational games using the genetic algorithm approach	Sideni Renato & Dante Augusto1998). This article describes the use of genetic algorithms and how they are implemented in educational computer games. It shows the importance of the use of information technologies since through learning games the task of learning is made easier for students, and teachers can make use of these tools to improve teaching-learning.
A model for designing smart teaching-learning systems using case-based reasoning.	Martínez Sanchez et al. (2009) This article describes the smart Teaching-Learning systems, with the purpose of understanding their importance, exposing the advantages and models that favor the creation of these systems. Likewise, algorithms are presented by means of known cases, and their adaptation to new problems, giving solutions to students and teachers by means of artificial intelligence.
The Transition from LMSs to Smart Learning Systems in Higher Education Higher Education	Zapata-Roz (2018) This article mentions the use of artificial intelligence today, and how it is a means of support for the pedagogical area and to provide resources in a better way in teaching, which can respond to the demand for knowledge and skills development of students. describes learning and teaching strategies, as well as the importance of technological services that allow providing teaching to university students both local and foreign.
Data mining: prediction of school dropout rates using the decision tree algorithm and the k-nearest neighbor algorithm	Valero Orea et al. (2005) This article mentions the importance of data mining to obtain knowledge of the information about students, useful for the creation of strategies that help students to improve. In the development of this article, we work around 2 algorithms: Classification tree algorithm: This algorithm generates a decision tree recursively by considering the criterion of the highest proportion of information gain, i.e., it chooses the attribute that best classifies the data. K nearest neighbors' algorithm: The nearest neighbors to an instance are

	obtained, in the case of continuous attributes, using the Euclidean distance over the n possible attributes. The result of the classification by this algorithm can be discrete or continuous.

Dai et al. (2021) start from existing data analysis methods and employ two models based on AHP-FCE and GA-BP as well as questionnaires to evaluate CCNU smart classrooms.

Venkatesh & Sathyalakshmi (2020) propose a new framework, personalized bee recommender for e-learning (PBReL), based on artificial bee colony (ABC) optimization, to build a recommendation structure by clustering K-means.

Ouf et al. (2017) address a detailed study addressing research works that apply ontology within the learning environment. Most of these studies focus on personalizing e-learning by providing learners, appropriate learning objects, ignoring the other components of the learning process.

Zhi-Ting et al. (2016) discusses the definition of smart education and presents a conceptual framework. A four-level framework of smart pedagogies and ten key characteristics of smart learning environments are proposed to foster smart learners to master the knowledge and skills of 21st century learning.

Spector (2014) suggest that a convergence of advances and developments in epistemology, psychology, and technology provide a foundation for planning and implementing smart learning environments.

Hoel & Mason (2018) examine findings from the smart education research community and the ITLET standards community to identify how evolving conceptual frameworks could inform specification work that stabilizes core terminology (e.g., as in smart technologies) in order to promote innovation.

Taisiya et al. (2013) examine the Smart Learning education system through a SWOT analysis of Korean public education. Thus, this study provides strategic implications for countries that are in the process of promoting the Smart Learning educational program.

Uskov et al. (2015) present the ontology developed for Smart Classroom Systems, which helps to understand and analyze current Smart Classroom Systems and to identify the features, hardware, software, services, pedagogy, and activities related to teaching and learning of the next generation of Smart Classroom Systems. the next generation of Smart Classroom Systems.

Carrauana Martin et al. (2019) make a systematic review of the literature to understand how this term is used, what technologies underpin it, and what promises are made. They conclude that, although the term is fuzzy, there are currently several advances that can make educational technologies much more adaptive to the learner and thus underpin learning in a smarter way.

Palanivel (2020) The aim of their research is to study emerging technologies to design a smart educational system.

Kim et al. 2011) propose a new notion of service that provides context awareness to smart learning content in a cloud computing environment. They suggest the elastic concept of four smarts (E4S)-smart pull, smart prospect, smart content, and smart push for cloud services, so that smart learning services are possible.

Sulkowski et al. (2021) analyze the impact of technology on changes in higher education with an indication of the model of future trajectories of education in the Economy 5.0 trend.

Novaliendry et al. (2020) explain the process of designing Android-based digital simulation learning media. The main reasons behind this research are a) the poor optimization of smartphones in learning, b) the visualization of learning media used today is less attractive, and c) the poor feasibility of current learning media.

Hwang (2014) presents the definition and criteria of smart learning environments from the perspective of context-aware ubiquitous learning.

Kinshuk et al. (2016) examines some challenges in education with a view to revolutionizing current learning environments into smart learning environments and offers new suggestions for technological solutions. In addition, this paper advocates for a transformation of current learning environments into smart learning environment.

Bdiwi et al. (2019) investigate the impact of teacher position on the performance of higher education students. A new pedagogical approach based on collaborative learning due to the design of a smart learning environment (SLE) is used.

Ha & Lee (2019) study the perceptions of elementary school teachers on issues related to smart learning to suggest a better training program for future teachers to support students' smart learning in classrooms.

Scott & Benlamri (2010) describe a cost-effective infrastructure for building ubiquitous collaborative learning spaces. It uses techniques from the semantic web and ubiquitous computing to build a learner-centric service-based architecture to transform existing traditional learning spaces (e.g., classrooms, computer labs, meeting rooms, and hallways) into ambient smart learning environments.

Zhuang et al. (2017) describe and analyze the characteristics of typical learning environments in smart cities, as well as the relationship of these learning environments.

Borawska-Kalbarczyk et al. (2018) characterize smart pedagogy (smart teaching and learning) in the context of the rapidly evolving digital world.

Kem (2022) discusses personalized and adaptive learning platforms, approaches and solutions applied in current eLearning systems.

Putro et al. (2018) the purpose of their study is to do a systematic literature review (SLR) of the need for smart technology for group training in a smart learning environment.

Chen et al. (2021) The purpose of their study is to comprehensively review the field of smart learning research by conducting a thematic model analysis of 555 publications on smart learning collected from the Scopus database.

Gambo & Shakir (2021a) describes a method for mapping learner actions (metacognitive skills) in a self-regulated smart learning environment to learning styles.

Sungkur & Maharaj (2022) advocate the use of SMART Learning Environments capable of taking into account learners' individualities and providing personalized learning.

Lu et al. (2018) present a new robot, called a Smart Learning Companion (SLP), which adopts self-determination theory (SDT) as a design principle to provide a more enjoyable learning experience and better motivate learners during their interaction with the robot.

Elhoseny et al. (2018) uses new smart learning technology to build a learning analytics framework that dissects measures of learner ability, meta-ability, and certainty in a smart learning environment.

Brusilovsky et al. (2023) set a clear architectural goal to aim for to facilitate the integration of SLC into modern course management tools and learning platforms.

X. Liu et al. (2015) propose a theoretical model for smart learning, with the goal of providing a research framework for smart learning.

Koper (2014) explores the conditions that Smart Learning Environments (SLE) should meet to stimulate better and faster learning.

Gambo & Shakir (2021b) conduct a systematic review to explore models, design tools, support approaches and empirical research on the self-regulated learning process in the Smart Learning Environments.

Garcia-Tudela et al. (2021) conduct basic research focused on the analysis of scientific advances related to Smart Learning Environments.

Hammad & Ludlow (2016) propose a structural framework for successfully implementing smart learning environments in the context of smart city governance. It reflects on certain challenges and proposes some directions for the future.

Zhang & Chang (2016) provide a brief overview of theories and research in the field of modern measurement and testing theory, also known as smart testing, and discusses how smart testing relates to smart learning concepts and practices.

Freigang et al. (2018) present the most recent results of an empirical study conducted to clarify the role of SLE and their design requirements, while taking into account the aforementioned framework conditions for didactics-based models of adult education.

Mitrofanova et al. (2019) studied the various methods and tools of intellectual analysis applied in Educational Data Mining (EDM), we have classified them according to the objectives and stages of application, which allowed us to reveal theoretical and practical directions of development and understanding of smart education.

Balyk & Shmyger (2017) discuss the transformation of the educational paradigm of higher education from e-learning to SMART-learning and describe theoretical and practical aspects of digital competence training of future teachers in the context of creating new knowledge in the SMART-University environment.

Boulanger et al. (2014) present a framework called SCALE that tracks finer-level learning experiences and translates them into opportunities for personalized feedback to address different degrees of personalization in online learning.

Huang et al. (2013) They analyze the differences of smart learning environment and digital learning environment from learning resources, learning tools, learning communities, learning communities, teaching communities, ways of learning and ways of teaching, and then we propose a system model and a TRACE3 functional model of "smart" learning environment.

Lister (2022b) explore possible ways to assess the implicit learning that may be present in autonomous smart learning activities and environments, reflecting on previous phenomenographic research on smart learning activities positioned as local journeys in connected urban public spaces.

Kaur & Bhatia (2021) offer a two-dimensional scient metric analysis of the literature on smart education from the context of educational and research areas.

García-Tudela et al. (2023) aim to identify the similarities and differences between the Future Classroom Lab (FCL) developed in the Spanish formal educational context in relation to SLE theory.

Bain & Zundans-Fraser (2014) describe the theory and research literature on which Smart Learning (SL) is based, including a description of the context and need for the initiative.

Mulyadi et al. (2022) examine the explanatory approach in addressing SL by advancing online learning sources.

Shi et al. (2022) discuss the spiral development of information literacy that enables the smart learning environment.

Singh (2022) identifies the elements and approaches to learning that could lead to a stable, coherent and comprehensive understanding of smart learning environments, thus providing the development of standards for learning, education.

Yoo et al. (2015) review ten case studies that address the development and evaluation of such a tool to support students and teachers using educational data mining techniques and visualization technologies. In the present study, a conceptual framework based on Few's dashboard design principles and Kirkpatrick's four-level evaluation model was developed to review educational dashboards.

Gambo & Shakir (2021c) explore the metacognitive components in the smart learning environment to propose the hybrid model, called MSLEM: Metacognitive Smart Learning Environment Model, which can help researchers to provide a personalized learning environment to support the online learning process.

Ilkou & Signer (2020) propose the innovative combination of a knowledge graph that represents what one has to learn and a learning path that defines in which order things are to be learned.

García-Sigüenza et al. (2023) propose an Artificial Intelligence (AI) model for a learning system that achieves this purpose. It is based on a learning model called CALM (Customized Adaptive Learning Model), which offers personalized learning through different learning paths and adapts to each learner by offering a specific activity at each moment.

Al-Kindi & Al-Khanjari (2019) address the concept and shows how to improve current Learning Management Systems (LMS). Hu (2022) presents precision education that aims to regulate student behaviors through Learning Analytics Dashboard (LAD) in AI-supported smart learning environment (SLE).

Lister (2022a) examines teaching practice in the Faculty of Education, University of Malta, conducting smart learning sessions as part of Technology-Enhanced Learning (TEL) units of study in the Bachelor of Education and Master of Teaching and Learning programs between 2017 and 2019.

Yassine et al. (2016) suggest the main features to consider when developing a learning analytics tool to measure and assess the learning outcomes of any course.

Peng et al. (2019) explore the core concept of a new form of personalized learning and build an appropriate framework in order to provide a reference for academics to conduct follow-up research and educators to explore practical ways to implement personalized and adaptive learning in the era of automated learning support systems.

Sangadji (2018) describes how a smart learning environment mobilizes on students' learning performance.

Junmei & Boqin (2020) construct the teaching mode of smart learning with the support of smart learning theory and smart learning environment, and apply it to the teaching practice of basic computer science courses in universities.

Lister (2021a) investigates smart learning conceptualized as real-world journeys formed by a series of geospatially relevant points of interest related to a learning topic, with digital interactions providing access to context-aware content.

Ullah et al. (2021) offers an extended model of technology acceptance that could help decision makers create a smart learning environment for educational institutes in emerging economies.

Lin (2019) proposes an inverted classroom with a smart learning diagnostic system to support a software engineering course. Coombs & Bhattacharya (2018) explore the nature of the conceptual framework of a sustainable learning environment in terms of smart thinking and learning tools and how these enable cognitive literacy.

Chung & Seomun (2021) analyze health issues related to high school students learning using smart devices using the grounded theory approach.

Lister (2021b) discusses the concepts of a pedagogical model based on the complexity of participants' experience to support smart learning activities.

Villa-Torrano (2022) focuses on the problem of how to support collaboration by detecting Socially-Shared Regulation of Learning (SSRL) patterns using data from SLE.

Ouadoud et al. (2020) reflects on the conditions for creating a real LMS between learners and teachers.

D. Liu et al. (2017a) discuss smart learning environments more broadly, integrating both formal and informal learning, as well as physical and virtual spaces in urban learning scenarios.

Frankl & Bitter (2013) describe the benefits to the community and all parties involved (defined as a win-win solution), as well as factors that can influence collaboration. The design principles of SLE, Smart Learning Communities (SLC).

Tabuenca et al. (2021) present a comprehensive characterization to describe SLEs through their possibilities, the technologies used and the pedagogical approaches considered in the selected articles. As a result, specific basic functions of SLE are identified and explained.

Şerban & Ioan (2020) propose a new learning design based on collaborative learner participation.

Al-Hamad et al. (2020) investigate the reality of using smart devices in teaching and learning in Jordanian universities from the instructors' perspective.

Sultana & Khalil (2017) elucidate the characteristics of smart learning. It also collects the opinions and perceptions of university professors on the acceptance of smart learning in their higher education institutions.

Kausar et al. (2020) comprehensively and systematically review Smart Learning Analytics (SLA) trends from the perspective of different types of analytics and various decision support systems in which learning analytics intervention is designed.

Rosmansyah et al. (2022) defines smart learning as a hybrid learning system that provides learners and other stakeholders with an enjoyable learning process while achieving learning outcomes as a result of the smart tools and techniques employed.

D. Liu et al. (2017b) explains the relationship between learning and smart cities, to know the state of smart learning in China in specific domains of digital campus, digital classrooms cooperative universities and smart learning industries.

Elhoseny et al. (2017) propose a personalized ubiquitous smart teaching and learning system using Internet of Things (IoT), big data, supercomputing and deep knowledge to improve the advancement, management and transmission of teaching and learning in smart social environments.

Mikulecký (2022) presents the latest developments in the field of ubiquitous and context-aware learning (smart learning) in a special type of smart environments, restricted to the case of smart workplaces.

Bahuguna et al. (2018) introduces the concept of augmented reality through smartphones. By introducing augmented reality into the educational system, teachers can convey their knowledge in a more valuable and engaging way.

Agbo et al. (2019) discuss the characteristics of SLE that are relevant to teaching programming and general design features for developing SLEs.

Li & Wong (2021) present a review of the literature on smart learning in order to provide an overview of its latest developments in research and practice.

Nguyen et al. (2022) explore how teachers in the Smart Learning Project at Khon Kaen University (KKU) use the concept of smart learning and innovation to manage their classroom in the digital learning environment.

Strategies

It is important to have a good base to be able to represent the essential information to solve the problem, the bases are studies and sciences that have evolved in the last 30 years and are described below: it tells us that a simple and practical teaching system must be developed to empower the educator of the future. With this goal in mind, we will develop a strategy, supported by neuroscience, neurolinguistic programming, coaching and personal development.

In addition, and as we have seen previously, knowledge in mathematics, Spanish and science should be considered, through evaluation according to the educational level, to determine initial parameters and the objectives to be achieved.

Finally, the design of strategies that help strengthen cognitive skills, materials and extracurricular activities that are attractive and personalized, as well as evolutionary so that we obtain an integral tool.

Some of the points to be considered are the following:

- Initial assessment of mathematics, literacy and science skills according to academic level.
- Assessment of the cognitive skills of individuals according to their age.
- Design materials to reinforce knowledge according to the educational level.
- Study the evaluation parameters of the individual's cognitive skills.
- Create activities with different levels of difficulty to strengthen mental processes.
- Develop interactive activities related to the topics to be reinforced.
- Follow-up of evaluations to propose learning paths in an individualized and automatic way.
- Parameters of objectives to be achieved.

The proposal to use a genetic algorithm is to take the values of the evaluations and match them with the quantitative values assigned to the different materials and activities within the system and thus propose the activities that best fit the level of evaluation that the user has at the time of using the application.

In order to achieve this, the individual must be defined in aspects such as the knowledge area, which is based on mathematics, reading, writing, science; the cognitive area and consider memory, attention, reasoning; and the skills area.

Mathematical modeling

The mathematical model of the problem is developed, focused on increasing students' school performance through Smart learning. This is intended to help maximize personalized learning, optimizing the use of technology to increase the overall average of students.

In order to optimize our objective function, the following decision variables are taken into account:

- X: Average obtained in school
- Y: Average obtained in the platform

The following objective function is proposed through the variables:

$$\text{Maximize } Z = \sum_{i=1}^{n} (X_i + Y_i).$$

Table 2. Mathematical model constraints.

tions	ym	t to
e of school students		
e number of students on the platform		
pent using technology		nin y ≤ 90 min
logy devices		ailability
t connectivity		nb
al resources		ilability
resources		ailability

When z is the total of the final school average plus the final average obtained in the platform, these are subject to both averages must be greater than 6, the time of uses of technology for learning must be greater than or equal to 20 minutes and less than or equal to 90 minutes of daily use, as well as the availability of technological devices with internet connectivity of at least 5 mb, in addition to the financial and human resources allocated to education does not exceed the current availability.

Technical specifications

To carry out the execution of the genetic algorithm code through the instances created, Google colab is taken into account as the development and execution environment, as it is an emulator that allows the writing and execution of Python code from the browser, with the advantage that it is not necessary to generate any configuration on the computer and it can be shared and worked on simultaneously as long as there is an internet connection.

The specifications with which it runs are:

Table 4. Technical specifications

	Total	**Used**
RAM Memory	12.7 GB	0.9 GB
Hard Disk	107.7 GB	26.9 GB

Code

A Python code was generated that implements independent functions for each part of the genetic algorithm, these are: the selection method, the fitness evaluation, the crossover and the mutation. Within the logic of the genetic algorithm, the previous generation is replaced with the newly created one and the best individual is identified.

The code was built to accept specific parameters such as the number of generations to be generated and the value of the mutation rate, so that they can be adjusted to find the best possible combination. In the current configuration, we are working with a population of 100 individuals, 50 generations and a mutation rate of 0.01.

The pseudocode of the genetic algorithm implemented for this study is shown below:

```
Algorithm AlgorithmGeneticAlgorithm(initialpopulation, generations, mutationRate)
currentpopulation <- initialpopulation

Write("InitialPopulation:")
For each individual in populationCurrent Do
Write(individual)
EndFor

For generation <- 1 To generations Do
parents <- selectForRule(currentPopulation, Length(currentPopulation))
NewPopulation <- crossParents(parents)
NewPopulation <- mutatePopulation(NewPopulation, mutationRate)
populationCurrent <- NewPopulation

bestIndividual <- getMaxMaximum(populationCurrent, fitness)
Write("Generation ", generation, ": ", bestIndividual, " (Aptitude: ",
aptitude(bestIndividual), ")")
EndFor

Return GetMaxMaximum(currentPopulation, fitness)
EndAlgorithm

# Convert the DataFrame to a list of tuples to use as initial population
population_initial <- ConvertDataFrameAListTuples(dataRandom)

# Run the genetic algorithm with n generations
bestSolution <- geneticAlgorithm(population_initial, 50)
```

Complexity of the algorithm

To calculate the complexity of the algorithm, an evaluation of each of the functions that compose it is performed and finally the sum is performed. The results obtained are described below:

- Function aptitude= O(1)
- Function selection by roulette= O(n2)
- Function to cross parents= O(n)
- Mutate population function= O(n)

Finally, the total complexity is:

$$O(1) + O(n^2) + O(n) + O(n) = O(1+n^2+2n)$$

Instances used

The instances used for algorithm experimentation are MATRICULA, C_SPANISH, C_MATHEMATICS, C_SCIENCES, PROM_T_USE_TECH, DT, PROM_PLAT as shown in the following example:

MATRICULA	C_SPANISH	C_MATHEMATICS	C_SCIENCES	PROM_T_USE_TECH	DT	PROM_PLAT	CI
00001	9	9	5	57	0	7	0
00002	9	6	5	87	0	7	0
00003	7	5	5	31	0	9	0
00004	10	7	6	27	1	7	0
00005	5	6	9	29	0	6	1
00006	7	7	5	48	0	8	1
00007	8	6	8	20	1	7	1
00008	10	10	6	70	1	5	1
00009	8	8	5	43	1	8	0
00010	9	10	9	43	1	6	1

Figure 4. Example of instance used.

Below is a link to the instances with which the code execution can be carried out to complement the experimentation: https://github.com/laos89/sl_ga_instances

Results

As we can see, the individual generated in the last programmed generations has a high score in each of the items that are evaluated, so that individuals have a high fitness value, with this we prove that the use of technology over time influences the qualifications of a student.

```
Generation 45: ('00204', 10, 10, 10, 10, 10, 10, 10) (Fitness: 70)
Generation 46: ('00124', 10, 10, 10, 10, 10, 10, 10) (Fitness: 70)
Generation 47: ('00046', 10, 10, 10, 10, 10, 10, 10) (Fitness: 70)
Generation 48: ('00477', 10, 10, 10, 10, 10, 10, 10) (Fitness: 70)
Generation 49: ('00046', 10, 10, 10, 10, 10, 10, 10) (Fitness: 70)
Generation 50: ('00154', 10, 10, 10, 10, 10, 10, 10) (Fitness: 70)
```

Figure 5. Example of genetic algorithm result.

4 Conclusions

Genetic algorithms are of great importance for problem solving, they can be applied to Smart learning issues, their application in this context offers a potential to support students in their academic performance.

In Mexico there is no official Smart learning system that works for educational institutions. Knowing that a large part of the population has smart devices and that since the COVID-19 pandemic many of the classes had to migrate to virtual classes and that today technological tools are still used to follow up cases, this medium can be used as a support for both students and teachers to have tools to improve the students' academic performance to avoid, to a great extent, their dropout.

References

Agbo, F. J., Oyelere, S. S., Suhonen, J., & Tukiainen, M. (2019). Identifying potential design features of a smart learning environment for programming education in Nigeria. *International Journal of Learning Technology*, 14(4), 331–354. https://doi.org/10.1504/IJLT.2019.106551

Al-Hamad, N. Q., AlHamad, A. Q., & Al-Omari, F. A. (2020). Smart devices employment in teaching and learning: Reality and challenges in Jordan universities. *Smart Learning Environments*, 7(5). https://doi.org/10.1186/s40561-020-0115-0

Al-Kindi, I., & Al-Khanjari, Z. (2019). The Smart Learning Management System (SLMS). 4th free and open source software conference.

Antequera Guerra, A. T. (2013). Khan academy: Una experiencia de aula en secundaria. 83, 199–209.

Arranz de la Peña, J., & Parra Truyol, A. (2007). Inteligencia artificial generativa y Universidad Carlos III.

Bahuguna, Y., Verma, A., & Raj, K. (2018). Smart learning based on augmented reality with android platform and its applicability. International Conference on Internet of Things: Smart Innovation and Usages, 1–5. https://doi.org/10.1109/IoT-SIU.2018.8519853

Bain, A., & Zundans-Fraser, L. (2014). Smart learning: Theory and research to practice.

Balyk, N., & Shmyger, G. (2017). Formation of Digital Competencies in the Process of Changing Educational Paradigm from E-Learning to Smart-Learning at Pedagogical University. Studio NOA for University of Silesia in Katowice.

Bdiwi, R., de Runz, C., Faiz, S., & Ali Cherif, A. (2019). Smart learning environment: Teacher's role in assessing classroom attention. *Research in Learning Technology*, 27.

Borawska-Kalbarczyk, K., Tołwińska, B., & Korzeniecka-Bondar, A. (2018). From Smart Teaching to Smart Learning in the Fast-Changing Digital World. 28-noviembre-2018, 23–39. https://doi.org/10.1007/978-3-030-01551-0_2

Boulanger, D., Seanosky, J., Kumar, V., Kinshuk, Panneerselvam, K., & Somasundaram, T. S. (2014). Smart Learning Analytics. *Emerging Issues in Smart Learning*, 289–296. https://doi.org/10.1007/978-3-662-44188-6_39

Breznitz, S. (2011). CogniFit training: The key to cognitive vitality. https://www.cognifit.com/pdf/experts/Cognitive_Vitality_2011.pdf

Brusilovsky, P., Edwards, S., Kumar, A., Malmi, L., Benotti, L., Buck, D., Ihantola, P., Prince, R., Sirkiä, T., Sosnovsky, S., Urquiza, J., Vihavainen, A., & Wollowski, M. (2023). Increasing Adoption of Smart Learning Content for Computer Science Education. Proceedings of the Working Group Reports of the 2014 on Innovation & Technology in Computer Science Education Conference, 31–57. http://dx.doi.org/10.1145/2713609.2713611

Carrauana Martin, A., Alario-Hoyos, C., & Delgado Kloos, C. (2019). Smart Education: A Review and Future Research Directions. UCAml.

Centro Virtual de Aprendizaje. (s/f). Tabla comparativa PISA - ENLACE [dataset]. Recuperado el 1 de octubre de 2023, de http://www.cca.org.mx/ps/profesores/cursos/ed129_2/html/m04/tema02/tabla_pisa_enlace.pdf

Chen, X. C., Zou, D., Xie, H., & Wang, F. L. (2021). Past, present, and future of smart learning: A topic-based bibliometric analysis. *Int J Educ Technol High Educ* 15-enero-2021, 18(2). https://doi.org/10.1186/s41239-020-00239-6

Chung, M.-S., & Seomun, G. (2021). Health Issues with Learning to Use Smart Devices in the Digital Age: Using a Grounded Theory Approach. *Int. J. Environ. Res. Public Health*, 18(13). https://doi.org/10.3390/ijerph18137062

Coombs, S., & Bhattacharya, M. (2018). Smart Learning requires Smart Thinking: The Evolution of Sustainable Learning Environments. *Journal of Educational Multimedia and Hypermedia*, 27(4), 453–470.

Dai, Z., Sun, C., Zhao, L., & Li And, Z. (2021). Assessment of smart learning environments in higher educational institutions: A study using AHP-FCE and GA-BP methods. 23/02/2021. https://doi.org/10.1109/ACCESS.2021.3062680

Elhoseny, H., Elhoseny, M., Abdelrazek, S., & Riad, A. M. (2018). Evaluating Learners' Progress in Smart Learning Environment. Proceedings of the International Conference on Advanced Systems and Informatics 2017. Springer International Publishing., 734–744.

Elhoseny, H., Elhoseny, M., Abdelrazek, S., Riad, A. M., & Hassanien, A. E. (2017). Ubiquitous smart learning system for smart cities. IEEE International Conference on Computing and Information Systems, 329–334. https://doi.org/10.1109/INTELCIS.2017.8260058

Estévez Valencia, P. (1997). Optimización mediante algoritmos genéticos (Vol. 109). Anales del Instituto de Ingenieros de Chile.

Frankl, G., & Bitter, S. (2013). Collaboration Is Smart: Smart Learning Communities. International Workshop on Human-Computer Interaction and Knowledge Discovery in Complex, Unstructured, *Big Data*, 293–302. https://doi.org/10.1007/978-3-642-39146-0_26

Freigang, S., Schlenker, L., & Köhler, T. (2018). A conceptual framework for designing smart learning environments. *Smart Learning Environments*, 5(27). https://doi.org/10.1186/s40561-018-0076-8

Gambo, Y., & Shakir, M. (2021a). An Artificial Neural Network (ANN)-Based Learning Agent for Classifying Learning Styles in Self-Regulated Smart Learning Environment. *International Journal of Emerging Technology in Learning*, 16(18), 185–199.

Gambo, Y., & Shakir, M. Z. (2021b). Review on self-regulated learning in smart learning environment. *Smart Learning Environments*, 8(12), 1–14. https://doi.org/10.1186/s40561-021-00157-8

Gambo, Y., & Shakir, M. Z. (2021c). WIP: Model of Self-Regulated Smart Learning Environment. 2021 IEEE World Conference on Engineering, 1–14. https://doi.org/10.1109/EDUNINE51952.2021.9429090.

García-Sigüenza, J., Real-Fernández, A., Molina-Carmona, R., & Llorens-Largo, F. (2023). Two-Phases AI Model for a Smart Learning System. International Conference on Human-Computer Interaction, 42–53. https://doi.org/10.1007/978

García-Tudela, P. A., Prendes-Espinosa, P., & Solano-Fernández, I. M. (2021). Smart learning environments: A basic research towards the definition of a practical model. *Smart Learning Environments*, 8(9), 1–21. https://doi.org/10.1186/s40561-021-00155-w

García-Tudela, P. A., Prendes-Espinosa, P., & Solano-Fernández, I. M. (2023). The Spanish experience of future classrooms as a possibility of smart learning environments. *Heliyon*, 9(8). https://doi.org/10.1016/j.heliyon.2023.e18577

Gestal Pose, M., Rivero Cebrián, D., Rabuñal, J. R., & Dorado, J. (2010). Introducción a los algoritmos genéticos y la programación genetica. Universidade da Coruña.

Ha, C., & Lee, S.-Y. (2019). Elementary teachers' beliefs and perspectives related to smart learning in South Korea. 12-febrero-2019, 6(3). https://doi.org/10.1186/s40561-019-0082-5

Hammad, R., & Ludlow, D. (2016). Towards a smart learning environment for smart city governance. Proceedings of the 9th International Conference on Utility and Cloud Computing, 185–190. https://doi.org/10.1145/2996890.3007859

Hoel, T., & Mason, J. (2018). Standards for smart education – towards a development framework. 2-marzo-2018, 5(3). https://doi.org/10.1186/s40561-018-0052-3

Hu, Y.-H. (2022). Effects and acceptance of precision education in an AI-supported smart learning environment. *Education and Information Technologies*, 27. https://doi.org/10.1007/s10639-021-10664-3

Huang, R., Yang, J., & Zheng, L. (2013). The Components and Functions of Smart Learning Environments for Easy, Engaged and Effective Learning. *International Journal for Educational Media and Technology*, 7(1), 4–14.

Hwang, G.-J. (2014). Definition, framework and research issues of smart learning environments-A context-aware ubiquitous learning perspective. *Smart Learning Environments*, 1(1), 1-14.

Ilkou, E., & Signer, B. (2020). A Technology-enhanced Smart Learning Environment based on the Combination of Knowledge Graphs and Learning Paths. CSEDU, 2, 461–468.

INEGI. (2022). Encuesta nacional sobre acceso y permanencia en la educación (ENAPE) 2021 (709/22). INEGI. https://www.inegi.org.mx/contenidos/saladeprensa/boletines/2022/ENAPE/ENAPE2021.pdf

INEGI. (2023). Estadísticas a propósito del dia mundial de la población (395/23). INEGI. https://www.inegi.org.mx/contenidos/saladeprensa/aproposito/2023/EAP_DMPO23.pdf

Junmei, H., & Boqin, L. (2020). Reform and Practice of University Computer Basic Course Teaching Mode Based on Smart learning. International Conference on Computer Science & Education, 272–275. https://doi.org/10.1109/ICCSE49874.2020.9201657

Kaur, A., & Bhatia, M. (2021). Scientometric Analysis of Smart Learning. *IEEE Transactions on Engineering Management*. https://doi.org/10.1109/TEM.2021.3124977

Kausar, S., Oyelere, S. S., Salal, Y. K., & Hussain, S. (2020). Mining Smart Learning Analytics Data Using Ensemble Classifiers. *International Journal of Emerging Technologies in Learning*, 15(12), 81–102. https://doi.org/10.3991/ijet.v15i12.13455

Kem, D. (2022). Personalised and Adaptive Learning: Emerging Learning Platforms in the Era of Digital and Smart Learning: Vol. 5(2). International Journal of Social Science And Human Research.

Kim, S., Song, S.-M., & Yoon, Y.-I. (2011). Smart Learning Services Based on Smart Cloud Computing. 9-agosto-2011, 11(8). https://doi.org/10.3390/s110807835

Kinshuk, Chen, N.-S., Cheng, I.-L., & Chew, S. W. (2016). Evolution Is not enough: Revolutionizing Current Learning Environments to Smart Learning Environments. *International Journal of Artificial Intelligence in Education*, 26, 561-581.

Koper, R. (2014). Conditions for effective smart learning environments. Smart Learning Environments, 1(5), 1–17. https://doi.org/10.1186/s40561-014-0005-4

Kuri Morales, A. F., & Galaviz, J. (2002). Algoritmos genéticos. IPN.

L. Uskov, V., Lakhmi C., J., & J. Howeltt, R. (2015). Smart Education and Smart e-Learning (Vol. 41). Springer.

Li, K. C., & Wong, B. T.-M. (2021). Review of smart learning: Patterns and trends in research and practice. *Australasian Journal of Educational Technology*, 37(2), 189–204. https://doi.org/10.14742/ajet.6617

Lin, Y.-T. (2019). Impacts of a flipped classroom with a smart learning diagnosis system on students' learning performance, perception, and problem solving ability in a software engineering course. *Computers in Human Behavior*, 95, 187–196. https://doi.org/10.1016/j.chb.2018.11.036

Lister, P. (2021a). Experiencing the smart learning journey: A pedagogical inquiry.

Lister, P. (2021b). The pedagogy of experience complexity for smart learning: Considerations for designing urban digital citizen learning activities. *Smart Learning Environments*, 8(8), 1–18. https://doi.org/10.1186/s40561-021-00154-x

Lister, P. (2022a). Future–Present Learning and Teaching: A Case Study in Smart Learning. Changing the Conventional University Classroom, 44, 61–79. https://doi.org/10.1108/S2055-364120220000044005

Lister, P. (2022b). Measuring learning that is hard to measure: Using the PECSL model to evaluate implicit smart learning. *Smart Learning Environments*, 9(14). https://doi.org/10.1186/s40561-022-00206-w

Liu, D., Huang, R., & Wosinski, M. (2017a). Contexts of Smart Learning Environments. *Smart Learning in Smart Cities*, 15–29. https://doi.org/10.1007/978-981-10-4343-7_2

Liu, D., Huang, R., & Wosinski, M. (2017b). Smart Learning in Smart Cities. *Lecture Notes in Educational Technology*. https://doi.org/10.1007/978-981-10-4343-7

Liu, X., Huang, R., & Chang, T.-W. (2015). Design of Theoretical Model for Smart Learning. State-of-the-Art and Future Directions of Smart Learning. Lecture Notes in Educational Technology. Springer, Singapore. https://doi.org/10.1007/978-981-287-868-7_9

Lu, Y., Chen, C., Chen, P., Chen, X., & Zhuang, Z. (2018). Smart Learning Partner: An Interactive Robot for Education. Artificial Intelligence in Education: 19th International Conference, AIED 2018, London, UK, 447–451.

Martínez Sanchez, N., García Lorenzo, M. M., & García Valdivia, Z. Z. (2009). 6(3).
y el educador del futuro. Grijalbo.

Mikulecký, P. (2022). Smart Environments for Smart Learning. DIVAI 2012 9th International Scientific Conference on Distance Learning in Applied Informatics, 213–222.

Mitrofanova, Y. S., Sherstobitova, A. A., & Filippova, O. A. (2019). Modeling Smart Learning Processes Based on Educational Data Mining Tools. Smart Education and e-Learning 2019, 144, 561–571. https://doi.org/10.1007/978-981-13-8260-4_49

Mulyadi, D., Huda, M., & Gusmian, I. (2022). Smart Learning Environment (SLE) in the Fourth Industrial Revolution (IR 4.0): Practical Insights Into Online Learning Resources. *International Journal of Asian Business and Information Management*, 13(2), 23. https://doi.org/10.4018/IJABIM.287589

Nguyen, L. T., Kanjug, I., Lowatcharin, G., & Manakul, T. (2022). How teachers manage their classroom in the digital learning environment – experiences from the University Smart Learning Project. Heliyon, 8(10).

Novaliendry, D., Darmi, R., Hendriyani, Y., & Azhari Azman, M. N. (2020). Smart Learning Media Based on Android Technology. International Journal of Innovation, Creativity and Change, 12(11.

OECD. (2016). Why They Fall Behind and How To Help Them Succeed. 9789264250246. https://www.oecd.org/pisa/keyfindings/PISA-2012-low-performers-Mexico-SPA.pdf

Ouadoud, M., Rida, N., & Chafiq, T. (2020). Designing the Self-Management Space of a New Smart Learning Management System. International Journal of Advanced Corporate Learning, 13(4). https://doi.org/10.3991/ijac.v13i4.15363

Ouf, S., Abd Mahmoud, E., S.E., S., & Helmy, Y. (2017). A proposed paradigm for smart learning environment based on semantic web. *Computers in Human Behavior*, 72, 796-818

Palanivel, K. (2020). Emerging Technologies to Smart Education (Vol. 68). International Journal of Computer Trends and Technology (IJCTT).

Peng, H., Ma, S., & Spector, J. M. (2019). Personalized adaptive learning: An emerging pedagogical approach enabled by a smart learning environment. *Smart Learning Environments*, 6(9). https://doi.org/10.1186/s40561-019-0089-y

Pulido, L. M. (2018). Aprendizaje y cognición-Modelos cognitivos. Fudacion Universitaria del área Andina.

Putro, B. L., Rosmansyah, Y., & Suhardi. (2018). Group Formation in Smart Learning Environment: A Literature Review. International Conference on Information Technology Systems and Innovation (ICITSI).

Rosmansyah, Y., Putro, B. L., Putri, A., Utomo, N. B., & Suhardi. (2022). A simple model of smart learning environment. Interactive Learning Environments. https://doi.org/10.1080/10494820.2021.2020295

Sangadji, K. (2018). Smart Learning Environment and its Impact on Student Learning Performance: A Theoretical Approach. International Journal of Education, Information Technology, and Others, 1(2). https://doi.org/10.5281/zenodo.2262455

Scott, K., & Benlamri, R. (2010). Context-Aware Services for Smart Learning Spaces (Vol. 3). IEEE Transactions on Learning Technologies.

Şerban, C., & Ioan, L. (2020). QLearn: Towards a framework for smart learning environments. *Procedia Computer Science*, 176, 2812–2821. https://doi.org/10.1016/j.procs.2020.09.273

Shi, Y., Peng, F., & Sun, F. (2022). A Blended Learning Model Based on Smart Learning Environment to Improve College Students' Information Literacy. *IEEE Access*, 10. https://doi.org/10.1109/ACCESS.2022.3201105

Sideni Renato, S., & Dante Augusto, C. B. (1998). Jogos Educativos computadorizados utilizando a abordagem de algoritmos genéticos. Universidade Federal do Rio Grande do Sul. Instituto de Informática. Curso de Pós-Graduação em Ciências da Computação.

Singh, A. (2022). Conceptual framework on Smart Learning Environment for the present and new century-An Indian perspective. Revista de educación y derecho = Education and law review, 25.

Spector, J. M. (2014). Conceptualizing the emerging field of smart learning environments. 16-octubre-2014, 1(2). https://doi.org/10.1186/s40561-014-0002-7

Sulkowski, L., Kolasinska-Morawska, K., & Seliga, R. (2021). Smart Learning Technologization in the Economy 5.0—The Polish Perspective. 5-junio-2021, 11(11). https://doi.org/10.3390/app11115261

Sultana, N., & Khalil, A. (2017). E-Adoption of Smart Learning in Higher Education. Journal of Social Sciences & Humanities, 25(2), 127–151.

Sungkur, R. K., & Maharaj, M. (2022). A Review of Techniques for Implementing SMART Learning Environments. Proceedings of the 3rd International Conference on Communication, Devices and Computing, 851. https://doi.org/10.1007/978-981-16-9154-6_69

Tabuenca, B., Serrano-Iglesias, S., Carrauana Martin, A., Villa-Torrano, C., Dimitriadis, Y., Asensio-Pérez, J. I., Alario-Hoyos, C., Gómez-Sánchez, E., Bote-Lorenzo, M. L., Martínez-Monés, A., & Delgado Kloos, C. (2021). Affordances and Core Functions of Smart Learning Environments: A Systematic Literature Review. IEEE Transactions on Learning Technologies, 14(2), 129–145. https://doi.org/10.1109/TLT.2021.3067946.

Taisiya, K., Ji Yeon, C., & Bong Gyou, L. (2013). Evolution to Smart Learning in Public Education: A Case Study of Korean Public Education. IFIP Advances in Information and Communication Technology.

Tapia Bernabé, I. R. (2019). El poder de Khan academy en el aprendizaje de las Matemáticas en el CONALEP. 120–142.

Ullah, N., Al-Rahm, W. M., Alzahrani, A. I., Alfarraj, O., & Alblehai, F. M. (2021). Blockchain Technology Adoption in Smart Learning Environments. https://doi.org/10.3390/su13041801

Valero Orea, S., Slavador Vargas, A., & García Alonso, M. (2005). Minería de datos: Predicción de la deserción escolar mediante el algoritmo de árboles de decisión y el algoritmo de los k vecinos más cercanos.

Venkatesh, M., & Sathyalakshmi, S. (2020). Smart learning using personalised recommendations in web-based learning systems using artificial bee colony algorithm to improve learning performance. 2020, 16(1), 101–117.

Villa-Torrano, C. (2022). Detecting patterns of Socially Shared Regulation of Learning in Smart Learning Environments. LASI-SPAIN, 165–170.

Yassine, S., Kadry, S., & Sicilia, M.-A. (2016). Measuring learning outcomes effectively in smart learning environments. 2016 Smart Solutions for Future Cities, 1–15. https://doi.org/10.1109/SSFC.2016.7447877.

Yoo, Y., Lee, H., Jo, I.-H., & Park, Y. (2015). Educational Dashboards for Smart Learning: Review of Case Studies. Emerging Issues in Smart Learning, 145–155. https://doi.org/10.1007/978-3-662-44188-6_21

Zapata-Roz, M. (2018). La universidad. La transición de los LMS a los Sistemas Inteligentes de Aprendizaje en Educación Superior. 57, 9. http://dx.doi.org/10.6018/red/57/10

Zapata-Roz, M. (2023). Inteligencia artificial generativa y .

Zhang, S., & Chang, H.-H. (2016). From smart testing to smart learning: How testing technology can assist the new generation of education. International Journal of Smart Technology and Learning, 1(1), 67–92.

Zhi-Ting, Z., Ming-Hua, Y., & Riezebos, P. (2016). A research framework of smart education. 31-marzo-2016, 3(4). https://doi.org/10.1186/s40561-016-0026-2

Zhuang, R., Fang, H., Zhang, Y., Lu, A., & Huang, R. (2017). Smart learning environments for a smart city: From the perspective of lifelong and lifewide learning. 30-octubre-2017, 4(6). https://doi.org/10.1186/s40561-017-0044-8