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Design of an adaptive hypermedia system to strengthen algebra learning skills of high school students

Diseño de un sistema hipermedia adaptativo para fortalecer habilidades de aprendizaje del álgebra de estudiantes de media superior

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Abstract

The national and international parameters of educational evaluation have provided a frame of reference to analyze and compare the performance of the students, however, in Mexico these results show a low educational level. Therefore, it is important to implement tools to reduce educational deficiencies. The objective of this work is to develop an Adaptive Hypermedia System (SHA), which considers the individual characteristics of students in order to adapt and present content based on competencies, for the development of algebra skills. This research project was carried out in three phases: Phase 1. The Protocol Test was applied to identify the academic entry profile of 185 high school students who were studying algebra. Phase 2. The learning strategies contained in the SHA were designed, taking into account two key approaches: research-action-development and the ESEAC scale. Finally, in Phase 3, the SHA was used as support for students who presented low performance in the subject of algebra that they are currently studying in their high school training, and thus determine the impact and effectiveness of this system.

Students, Adaptive Hypermedia System, academic performance

Resumen

Los parámetros nacionales e internacionales de evaluación educativa han proporcionado un marco de referencia para analizar y comparar el desempeño de los estudiantes, sin embargo, en México estos resultados evidencian un bajo nivel educativo. Por lo que es importante implementar herramientas para disminuir las deficiencias educativas. El objetivo de este trabajo es desarrollar un Sistema Hipermedia Adaptativo (SHA), el cual considera las características individuales de los estudiantes con el fin de adaptar y presentar contenidos basados en competencias, para el desarrollo de habilidades del álgebra. Este proyecto de investigación se llevó a cabo en tres fases: Fase 1. Se aplicó la Prueba Protocolo para identificar el perfil académico de ingreso de 185 estudiantes de educación media superior que cursaban la materia de álgebra. Fase 2. Se diseñaron las estrategias de aprendizaje que contiene el SHA, tomando en cuenta dos enfoques clave: la investigación-acción-desarrollo y la escala ESEAC. Finalmente, en la Fase 3 se utilizó el SHA como apoyo para los estudiantes que presentaban un bajo rendimiento en la materia de álgebra que actualmente cursan en su formación de preparatoria, y así determinar el impacto y eficacia de este sistema.

Estudiantes, sistema hipermedia adaptativo, rendimiento académico

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Introduction

Education is the cornerstone of global progress and well-being. For this reason, prestigious international institutions, including the United Nations (UN), have implemented various programmes throughout history to promote not only access to, but also the quality of education, since it is through education that problems such as poverty, social challenges, cultural barriers and even economic hardship can be addressed and combated.

In Mexico, the results obtained in the PLANEA test (Plan Nacional para la Evaluación de los Aprendizajes) have generated growing concern and highlighted the urgent need to improve the quality of education in the country; these periodic results have shown significant deficiencies in the performance of Mexican students in various areas of knowledge, including mathematics (INEE, 2019).

In response to the needs identified, it is essential to reflect on the teaching methods currently employed. This challenge is accentuated by the COVID-19 pandemic, which has rendered many of the traditional practices used in education obsolete. In this context, the need has arisen to adopt an approach that makes use of technological tools to facilitate teaching and learning. However, it is important to recognise that these technological tools have limitations in their ability to provide individualised guidance in the learning process.

Individualisation in education involves considering the interests, learning styles and proficiency levels of each learner, allowing resources and pedagogical strategies to be tailored to meet specific needs. By providing personalised guidance, a more inclusive and equitable learning environment is fostered, where each student has the opportunity to reach his or her full potential. This approach promotes a more effective and meaningful education, as it focuses on the holistic development of each student, recognising their strengths and areas for improvement. It also facilitates a closer bond between teacher and student, which strengthens the educational relationship (Wilson et al., 2017).

Ennouaman and Mahani (2017) emphasise the need to make educational resources available to all, while making learning available in an appropriate manner in terms of place, time and form. They recognise the importance of personalisation and adaptation in the educational process. On the other hand, Cueli et al. (2016) and Salcedo et al. (2016) have conducted significant research through the design and implementation of Adaptive Hypermedia Systems (AHS), with the purpose of improving the mathematics learning process at different educational stages. These researchers highlight the importance of adjusting educational content to the individual context of students, recognising their unique abilities, prior knowledge and learning styles. They consider it essential to develop educational systems that adapt to the specific needs of each student, providing a personalised and effective learning experience.

Adaptive Hypermedia Systems (AHS) enable the adaptation and personalisation of educational content by using hypermedia technologies that deliver information and resources in a flexible and dynamic way, taking into account the individual characteristics of each learner.

In the field of education, the personalisation of educational content has become a crucial challenge, especially in the current context, which requires forced changes in the teaching-learning process, in this sense, adaptive hypermedia systems emerge as a valuable solution. These systems have the capacity to offer the necessary flexibility to adapt educational content in an individualised way, taking into account the different abilities and characteristics of each student. In this way, a clear path towards the achievement of the established educational objectives can be ensured (Vera *et al*., 2014).

The main objective of this study is to improve the algebra learning process through the use of an Adaptive Hypermedia System (AHS). The research will focus on providing evidence that demonstrates the effectiveness and usefulness of this tool as a support for underachieving students who are taking algebra in their upper secondary education.

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Theoretical framework

Study of algebra

Algebra is a branch of mathematics that focuses on generalisations and abstract relationships between quantities, using symbols and letters to represent unknown numbers or variables. Learning algebra is the process by which students acquire the concepts, skills and strategies necessary to understand and use algebraic language, solve equations, manipulate algebraic expressions, and work with numerical patterns and relationships. Such learning is not limited to the mastery of formulas and procedures, but also involves developing more abstract and structured mathematical thinking. By studying algebra, students learn to identify patterns and regularities, to formulate and solve problems, to make evidence-based generalisations and to justify their reasoning logically (Kieran and Filloy, 1989).

Learning algebra has several stages and levels of complexity. It starts with fundamental concepts such as basic arithmetic operations and the representation of numbers by variables. It then progresses to more advanced topics such as linear equations, systems of equations, factoring, exponents, polynomials, functions and matrix algebra (Ricaldi, 2019).

Algebra is an essential tool in many disciplines, including science, engineering, economics and computer science. In addition, its study develops skills in critical thinking, problem solving, abstraction and logical reasoning, which are fundamental to intellectual development and preparation for careers in STEM (science, technology, engineering and mathematics) fields.

Algebra learning benefits from pedagogical approaches that foster conceptual understanding, authentic problem solving, connection to real-world situations, and the use of technology and digital tools to visualise and explore algebraic concepts.

Algebra in Mexico

In Mexico, the study of algebra at the upper secondary level is a fundamental part of the curriculum in basic education. In general, the focus of algebra study is on providing students with the necessary tools to solve complex mathematical problems and to understand and apply abstract concepts (Vergel, 2015).

The algebra curriculum at the upper secondary level in Mexico has been revised, with the aim of updating it and making it more relevant to the needs of students. Some of the topics covered in this syllabus include first and second degree equations, systems of linear equations, matrices, polynomials, functions and trigonometry.

When verifying the areas of opportunity for learning this branch of mathematics, it has been detected that students find algebra difficult to understand and apply in practice, which can affect their academic performance and their interest in this discipline (Miranda, 2016).

Adaptive hypermedia system

An adaptive hypermedia system (AHS) is a type of software that adapts to the user's needs and preferences, offering a personalised and relevant experience. It is essential to take into account the previous diagnosis in order to carry out an appropriate design. Through an optimal design, it is possible to propose hypermedia content, such as videos, images, text and links, which are presented in different ways according to the user's needs (Vera, et al, 2019).

The adaptive hypermedia system (AHS) refers to the set of actions that automatically are able to adapt according to certain characteristics by the user, it should be noted that this allows individual work, as it is flexible with respect to the material offered, based on the history according to navigation, domain, interests, etc.

An adaptive hypermedia system is a type of information system that dynamically adapts and personalises itself to the user according to their needs, preferences and context. Hypermedia refers to the combination of hypertext (interconnected texts) and multimedia (such as images, audio, video, etc.) to present information in a non-linear way.

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Adaptability in an adaptive hypermedia system implies that the system can adjust its content, structure and presentation in real time, depending on user characteristics and environmental conditions. This is achieved by collecting and analysing information about the user, such as their profile, interaction history, preferences, level of knowledge, situational context, among others (Nieto and Alexandra, 2019).

According to Rivera Chávez (2018) the adaptive hypermedia system uses artificial intelligence techniques, such as data mining, machine learning and personalised recommendation, to make decisions about what content to display, how to present it and how to organise it. For example, it can adjust the order of links or sections of information, select relevant images, provide additional explanations based on the user's level of knowledge, or even adapt the user interface to fit accessibility needs.

SHAs aim to improve the user experience by providing relevant and personalised information, facilitating navigation and content search, and adapting to changing user needs over time. These systems are used in a variety of areas, such as online education, content recommendation systems, adaptive learning environments and personalised web applications (Uribe, 2020).

An adaptive hypermedia system can be composed of several elements that work together to provide a personalised user experience, it is composed of 3 models (domain, user and adaptation), being the user model the source of information that forms a structured representation of the information collected about the user, this includes various characteristics, which depend on the scopes raised for the creation of the system, for example: demographic characteristics, interests, skills, presentation preferences, browsing history, among other relevant aspects. This model is used to personalise the user experience and guide system adaptation decisions (Wilson and Scott, 2017). While the adaptive model is the core component of the adaptive hypermedia system. Using artificial intelligence techniques, such as data mining and machine learning, the adaptation engine analyses the user model and makes decisions on how to adapt the content and presentation.

It can select relevant content, adjust the order of links, adapt the user interface. It is important to emphasise that the adaptation model follows adaptation rules, which are a set of guidelines and criteria that the adaptation engine uses to make decisions. These rules define how content is adapted based on the information available about the user and the context.

User experience

Knapp Bjerén (2003) defines user experience (UX) as the set of emotions, perceptions and sensations that a user experiences when interacting with a product, service or system. It is about understanding and designing every aspect of user interaction in order to provide an optimal, satisfying and effective experience.

At the very core of user experience lies a fundamental principle: empathy for the user. Designers and UX professionals do not only focus on technical and aesthetic aspects of design, but place special emphasis on deeply understanding the users they are meant to serve (Avila Muñoz, 2022).

The UX design process involves researching and gathering information about users, prototyping and testing with real users to iterate and continuously improve the product or service. In addition, it seeks to ensure that the product is accessible to all, regardless of their physical or cognitive abilities, thus promoting inclusion.

Usability testing

SUS (System Usability Scale) is a scale-based usability evaluation tool. It consists of a short, standardised questionnaire with 10 questions designed to measure users' subjective perceptions of the usability of a particular system. To answer these questions, participants use a 5-point Likert scale, where they express their degree of agreement or disagreement with statements related to the usability of the system. The main objective of SUS is to provide a quick and direct measure of usability as perceived by users (Brooke, 1986). This tool has proven valuable in obtaining information about users' overall impression of a system's ease of use, thus enabling designers and developers to make informed and effective improvements to achieve a more satisfying user experience.

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Action research and development

Action research-development stands out as a highly relevant option because it offers multiple advantages in the design, development and implementation of educational strategies. Its origin arises from a real need, identified through observation and understanding of the phenomenon under study. In addition, this methodology promotes reflection to identify the institutional elements that influence educational practice (Ortiz and Borjas, 2008), which is essential to address specific problems in a given context.

Methodology

This research project was carried out in three phases:

Phase 1. In this phase, the Protocol Test was used to identify the academic entry profile of 185 upper secondary education students taking the subject of algebra. This Protocol Test makes it possible to identify the most difficult subjects, the competences to be developed, the learning styles, the perception of digital content and the students' preferences.

Phase 2. Using the results obtained in phase 1, the learning strategies contained in the SHA were designed. To carry out this didactic design, two key approaches were taken into account: research-action-development, which made it possible to establish strategies, use them and verify their relevance according to the needs detected in phase 1, as well as Bernad's ESEAC scale. These learning strategies aim to empower students in their own learning process, fostering autonomy and the active construction of knowledge in accordance with the competences required for better academic performance.

Phase 3. In this phase the SHA was evaluated as a support tool in the learning process of algebra. During this phase, 16 students who had failed due to poor academic performance in the subject participated. The selection of the participants was carried out by means of informed consent, which made it possible to form two groups: the control group, made up of 8 students, and the experimental group, also made up of 8 students.

Design of the SHA

Taking into consideration the analysis of Phase 1 and 2 of the intervention, it was possible to obtain relevant data on the context of the students, highlighting the identification of the most difficult topics, the materials of interest, preferences in the predominant learning styles, as well as the perspective of the study of algebra with digital materials.

As mentioned above, an adaptive hypermedia system (AHS) involves several key actors interacting with each other to provide a personalised learning experience. Figure 1 shows that the actors that make up the SHA are: the learner, the teacher, the administrator and the database..

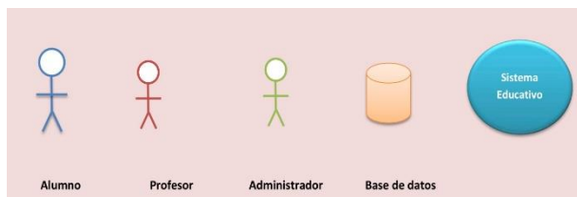

Figure 1 SHA actors
Source: own elaboration

For the analysis and design of the system, according to Ciccozzi, et. al., (2019) the use cases of the system have been established using Unified Modelling Language (UML), which is a standard modelling language used in software engineering to visualise, specify, build and document software systems. This modelling provides a set of graphical notations and tools to visually represent different aspects of a system, such as its structure, behaviour, interactions and relationships between its components (Figure 2).

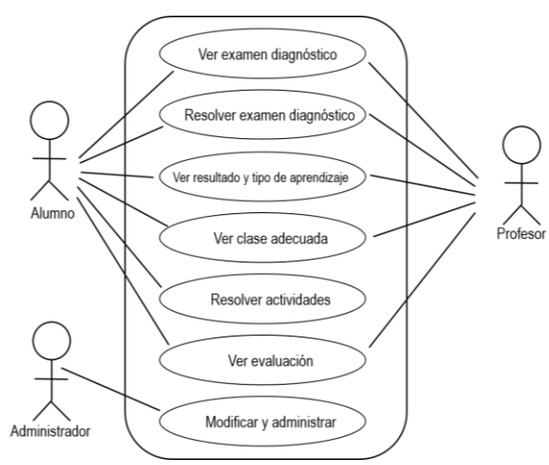

Figure 2 Use case modelling
Source: own elaboration

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Database

The SHA contains a section where all information is stored in a relational database, which has been carefully designed through a conceptual model. To achieve this, all the requirements necessary for the correct functioning of the system were first compiled in detail. Subsequently, a detailed database schema was designed, including complete descriptions of the entities, relationships and constraints, which is presented using graphical and textual concepts typical of the relational data model.

The initial model, which represents the fundamental structure of the database, is further refined into what we call a logical schema.

During this refinement process, ambiguities are removed and the technical and implementation aspects of the system are further defined. The result is a refined and detailed version of the database, which represents the foundation on which information is efficiently and reliably built and managed (Figure 3).

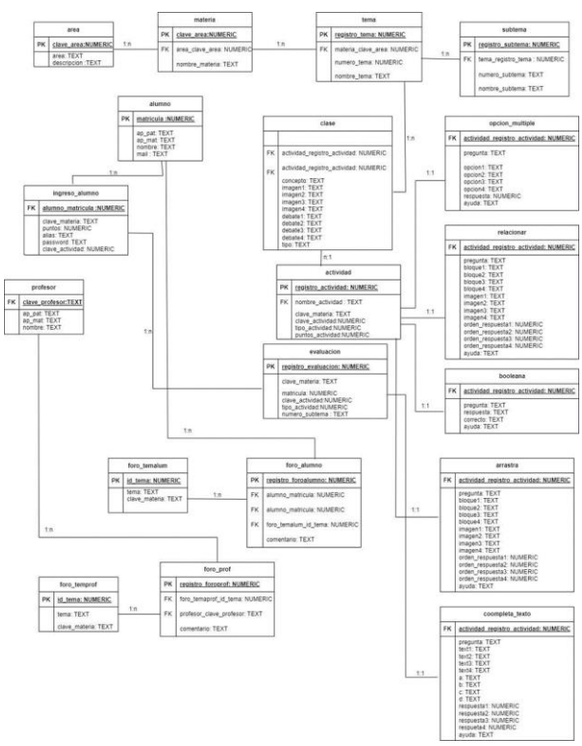

Figure 3 Relational diagram of the database
Source: own elaboration

Content description

For the development of the adaptive hypermedia system, several classes were designed to meet the needs of each type of learner. These lessons are available for consultation, allowing all learners to acquire the necessary knowledge in an immersive environment close to reality. In this way, students can make connections between new knowledge and previously acquired knowledge, as well as address future issues.

When accessing the SHA, the learner can observe and select his or her available subject, in this case: algebra. When entering the subject, the first thing that is displayed is a login screen, where the learner can log in with his/her account (Figure 4).

Figure 4 Login interface
Source: own elaboration

If you do not have an account, you have the option of registering via the "new student" button, where you fill in a form (Figure 5) and once successfully completed, you can log in from the welcome tab above.

Figure 5 Registration interface
Source: own elaboration

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When accessing the system, a welcome window is displayed containing a series of buttons named: start, content, activity, evaluation, forum and links, in addition to the name of the registered user and the score obtained up to that moment (Figure 6), which appears in the central part of the interface. In addition, a description of how the SHA works and some recommendations for its proper use are shown. Finally, a button to log out and exit the system is included.

Figure 6 Welcome interface
Source: own elaboration

In the section called <<Content>> you have access to all available learning materials (Figure 7). In this section there are several topics and types of content to explore, which correspond to the analysis of the algebra syllabus of a public upper secondary school in the state of Puebla.

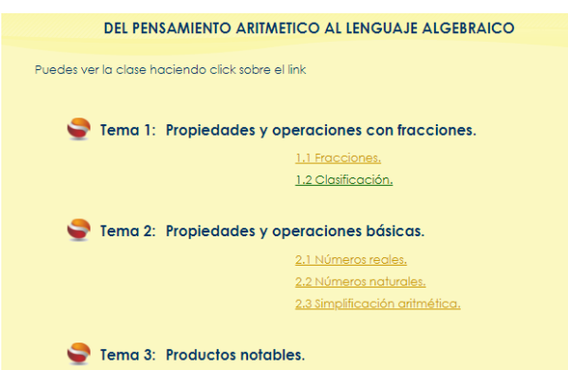

Figure 7 Content interface
Source: own elaboration

The SHA is integrated by an educational methodology focused on the use of various tools to teach and reinforce concepts to students in an effective and understandable way. The sections that comprise it are described below:

Topic discussion: information is handled in the form of a discussion, showing ideas that help the student to build a complete idea of the topic.

Topic image: The class is shown with a series of visually attractive images or everyday examples, with the aim of exemplifying the concept that is established in the learning process, in order to achieve a better understanding of the topic. analysing.

Concept application: this section includes the two sections mentioned above, showing images about the topic and the explanation or idea related to the image.

Video related to the topic: this section includes visual material (video type) where concepts that the student needs to learn are explained.

The design of the SHA contains an integral educational methodology, as it seeks not only to provide information, but also to stimulate critical thinking and the active participation of the student in the learning process. This is made possible by using a combination of discussions, images, explanations and videos, creating a dynamic and effective learning environment that enhances academic development and deep understanding of the topics covered.

An example of the interface corresponding to the <<Activity>>> section can be seen in Figure 8, where students participate in practical activities at the end of each class, which are related to the topic previously covered. The activities serve as an evaluation of the student's performance in the subject. It should be noted that several types of activities were designed to include a variety of learning approaches. These include Boolean (true or false) quizzes, multiple choice questions, text completion, concept matching and drag and drop. Each activity was designed to test understanding and assimilation of the content taught.

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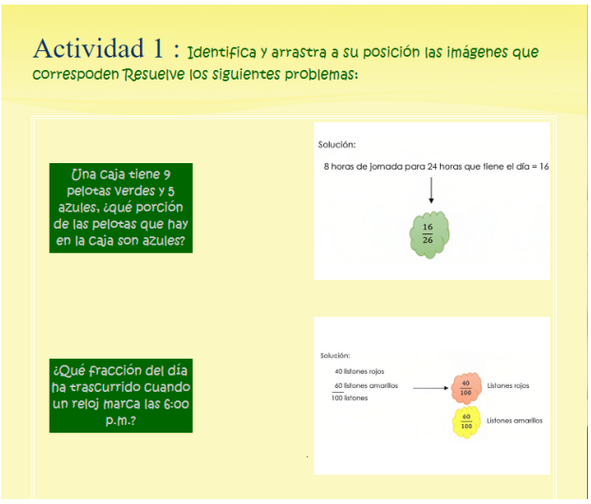

Figure 8 Activity interface
Source: own elaboration

In the process of performing these activities, the learner receives instant feedback from the system. If they provide an incorrect answer, they are shown the specific error and constructively provided with additional support material to reinforce knowledge, thus encouraging students to learn from their mistakes and improve their understanding. On the other hand, if the student answers correctly, they receive a congratulatory message, which helps to maintain their motivation and confidence in their learning abilities. This positive approach seeks to reinforce the knowledge acquired and to foster a positive attitude towards the learning process (Figure 9).

Figure 9 Evaluation and feedback interface
Source: own elaboration

In short, SHA implements practical activities and personalised feedback to assess and improve student performance. By using different types of activities and providing a balanced approach between remediation and recognition, it provides an enriching and effective learning experience for all students.

Results

Through phase 1, in which 185 students who take the subject of algebra of the curriculum belonging to an institution of Upper Secondary Level participated, a survey called "Protocol Test" was conducted on the current status of students, which is composed of 35 items that provided information on the most difficult topics, the skills to develop, learning styles, perception of digital content and student preferences. To mention some of the most relevant findings in this phase:

- Information was obtained on academic performance, considering the grade of 6.3 as the overall average obtained during the application of the survey.

- It was detected that 88% of the students present recurrent difficulties in solving problems with the following topics: operations with fractions, law of signs, hierarchy of operations, law of exponents and development of square binomial.

- The predominant learning styles are kinaesthetic (52%), visual (32%) and auditory (16%).

- The predominant thinker type is the Concrete Thinker (CP) with 68% weighting, while the Abstract Thinker (AP) has a null appearance.

In phase 2, the learning strategies were elaborated taking as a reference the diagnosis obtained in phase 1, in addition to the results of the research-action-development actions, which indicates that the description of reality is required. To this end, the 185 students mentioned above participated, used the strategies designed for the topics that represented the greatest difficulty, yielding relevant information on areas for improvement in the type of materials proposed, and based on this information, adjustments were made to the activities and subsequently implemented in the SHA.

In phase 3, a study was carried out with a total of 16 students who had low academic performance and were at risk of failing. This study was divided into two groups: a control group of 8 students and an experimental group of 8 students. The division of the groups was carried out under.

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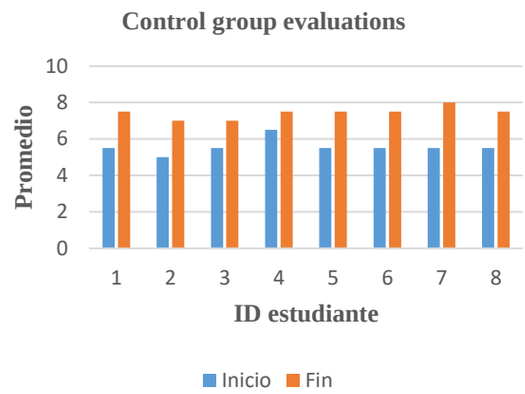
At the beginning, the most complex topics for the students were identified, as well as their preferences in terms of the type of materials they prefer to use to strengthen their learning in the area of algebra. These findings provide us with valuable information to adapt educational resources and provide more effective support to students in their learning process. The types of thinking described by the terms (PC) "concrete", (PT) "transitional" and (PA) "abstract" refer to the level of abstraction used in logic and problem solving, Table 1 describes the characteristics of each of the participants, as part of the safeguarding of information and confidentiality they were assigned a numerical ID to identify them, the control group is made up of the sequence from 1 to 8, while the experimental group is from 9 to 16.

ID Student	Predominant thinker type	Predominant learning style	Cognitive process	Grade obtained	
				U.1	U.2
1	PC	Kinesthetic	Analysis	5	6
2	PC	Kinesthetic	Analysis	5	5
3	PC	Kinaesthetic	Synthesis	5	6
4	PC	Visual	Analysis	6	7
5	PT	Kinesthetic	Synthesis	5	6
6	PC	Visual	Analysis	6	5
7	PT	Visual	Analysis	5	6
8	PT	Auditory	Synthesis	6	5
9	PC	Visual	Analysis	5	5
10	PT	Visual	Analysis	5	6
11	PT	Auditory	Synthesis	6	5
12	PC	Kinaesthetic	Synthesis	5	6
13	PC	Visual	Analysis	6	7
14	PT	Kinaesthetic	Synthesis	5	6
15	PC	Kinaesthetic	Analysis	6	6
16	PC	Kinaesthetic	Analysis	5	5

Table 1 Detected categories of the participating students
Source: Prepared by the authors

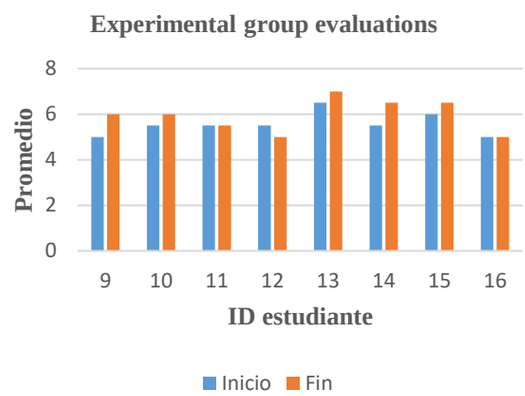
Over a period of 3 weeks, a regularisation course was held with 16 students. As part of the course planning, the teacher in charge of the assessment provided a study syllabus for all students. However, a differentiated approach was implemented for the control group, which received additional support through the use of the SHA. This system provided personalised coaching and specific support materials, tailored to the categories previously identified as areas of improvement for the students.

At the end of the sessions, the students took a final assessment in order to be able to accredit the algebra subject. Graph 1 shows the individual marks obtained, which clearly shows that the control group (ID 1 to 8) experienced a more notable improvement in their marks obtained at the beginning of the regularisation course up to the final assessment.



Graphic 1 Comparison of control group evaluations
Source: Own elaboration

On the other hand, Graph 2 shows the grades obtained by the experimental group (ID 9 to 16), where it does not show significant changes in their final grade.



Graphic 2 Comparison of experimental group evaluations
Source: Own elaboration

Subsequently, the SUS Test was administered to the control group in order to obtain their opinion on the usability of the SHA. By means of a short, standardised questionnaire consisting of 10 questions (Table 2), we sought to find out the students' general impression of the ease of learning, efficiency in performing tasks, comfort of use and other relevant aspects.

ID Question	Description of the question
1	I think I would use this system frequently.
2	I found the system unnecessarily complex.
3	I think the system is easy to use.
4	I think I would need the support of a person with technical knowledge to use this system.
5	I found the various functions of the system well integrated.
6	I think there was too much inconsistency in this system.
7	I imagine that most people would find it easy to learn how to use this system.
8	I found the system very tedious to use.
9	I feel confident using this system.
10	I needed to learn a lot of things before I could start working with the system.

Table 2 SUS Test Questions
Source: (Brooke, 1986)

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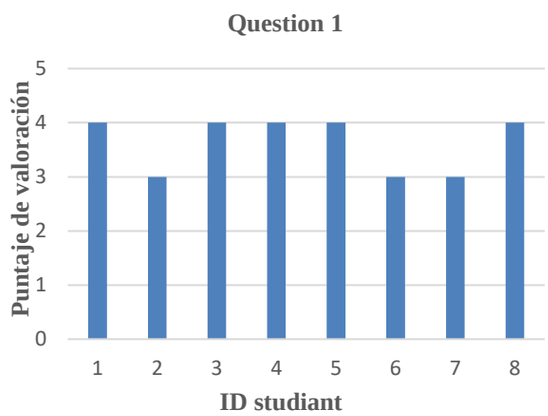
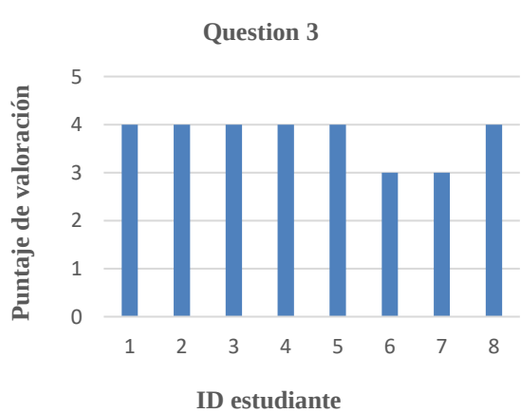
The results obtained from the application provided valuable feedback on the students' experience with the SHA. This allowed areas for improvement to be identified and adjustments to be made to optimise the usability of the system in order to improve the students' learning experience (Graphic 3).



Graphic 3 Students' assessment of SUS Question 1
Source: Own elaboration

The results of the usability test using the System Usability Scale (SUS) indicate that 5 of the 8 participating students responded with a score of 4 (strongly agree) to the question "I think I would use this system frequently", suggesting that the majority of students expressed a high intention to use the system frequently.

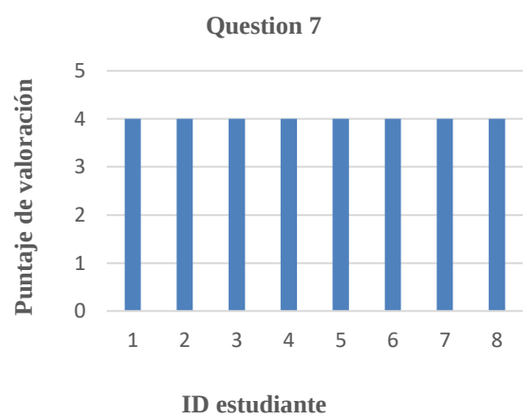
On the other hand, the remaining 3 students responded "agree" to the same question. This also indicates a positive perception towards frequent use of the system, albeit slightly less enthusiastic compared to the group of students who responded with a score of 4 (Graphic 4).



Graphic 4 Students' evaluation of SUS Question 3
Source: Own elaboration

The results of question 7 of the SUS questionnaire, which is "I imagine that most people would find it easy to learn to use this system" (Graphic 5), show a very positive and uniform perception among the 8 students who participated in the test. All students responded that they "Strongly agree" with the statement, indicating that each of them believes that the system is easy for most people to learn. This consistency in responses suggests a high confidence in the ease of learning the system by users.

When all participants agree that most people would find it easy to learn to use the system, this further reinforces the positive impression about the usability and accessibility of the evaluated product.



Graphic 5 Students' evaluation of SUS Question 3
Source: Own elaboration

In summary, the results of the SUS test indicate that students have a positive opinion about the ease of learning the system, suggesting that the design and structure of the SHA designed from this research favours a quick adaptation for most users. These results are encouraging and point to a satisfactory user experience and a willingness to use the system.

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Conclusions

The results obtained reveal significant findings regarding the academic performance of the control group over the experimental group.

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It was detected that the control group presented an improvement in their academic performance compared to the experimental group. This suggests that the use of SHA could have a positive impact on algebra learning and contribute to higher academic performance.

Furthermore, the results of the SUS test indicate that the control group has a positive opinion about the ease of learning of the adaptive hypermedia system. The results obtained indicate that the design and structure of the SHA developed from this research favour rapid adaptation for most users. The results are encouraging, as they point to a satisfactory user experience and a good predisposition to use the system. Although participants in the control group mention that the materials contained in the SHA were a resource that supported them in obtaining their final grade, it is recognised that there are areas for improvement in the visualisation of the activities. This could be due to several variables that should be considered for future research, for example, the implementation of adjustments in the design of the system and the evaluation of different teaching strategies in the context of the SHA.

In conclusion, this study has provided significant evidence on the effectiveness and positive perception of the adaptive hypermedia system in algebra learning. The results suggest that SHA has the potential to improve academic performance and provide a satisfactory user experience. The educational and scientific community is encouraged to continue to explore and refine the use of such systems in teaching algebra in order to promote more effective and enriching learning for students.

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