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Proposal of a System to Support the Learning of Fractions, Ratio and Proportion in Elementary School Students

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The academic work carried out in the elementary school during the confinement stage due to the pandemic experienced by the SARS COV2 virus was mostly through the Learn at Home program, which consisted of teaching classes on television, but the videos were recorded, which meant that not all students obtained the same level of knowledge, due to the particularities of each one or the complexity of the subject. In this work we address the problem referred to the need to regularize the students of sixth grade of Primary Education in the subjects of reason and proportion; for this we proposed to develop a web system that helps the student in their process through a method of personalized education, using adaptive learning. First, the student, when entering the system, solves a questionnaire, which places him in some stage of the learning process, which could be in the qualitative part of his proportional thinking, in the transition to the quantitative or in a totally quantitative stage. According to the stage in which the student is, the system provides activities for him to continue advancing in the development of his proportional thinking.

Keywords: digital educational materials, elementary school, ratio, proportion

Introduction

Not all people experience the learning process in the same way; for example, maturing times of the information received are different from one person to another, as well as the channels through which such information is processed or the mental patterns that are developed, to cite some of the factors that are involved in the student's learning process (Dongo, 2008). This implies that teaching methods should pay special attention to students' needs, abilities, perceptions, and prior knowledge in order to optimize their learning process, which translates into personalized education (Von Feigenblatt, Peña-Acuña, & Cardoso-Pulido, 2022).

UNESCO's position on personalized learning is that it should be a central objective of education systems, since it is the path to quality education (Meza Cortés, 2020).

In all times personalized education has been important since, by advancing at their own pace, each student reaches the objectives set, allowing the successful completion of each grade and level of studies, which translates into a high development of their skills to be able to perform in an increasingly complex society (Hernández, 2019). Currently, personalized education plays a fundamental role since, given the situation of confinement in

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which we found ourselves, due to the pandemic caused by the SARS-COV-2 virus, in all schools, education was provided in a non-face-to-face manner (Government of Mexico Blog, 2020). Since the return to face-to-face classes in August of this year, teachers have seen the need to regularize students, for which one way to do it would be precisely through the personalized education approach, by forming small groups of students who present similar characteristics in terms of previous knowledge, learning strategies and address the contents with a degree of difficulty that prevails in that team.

On the other hand, referring to all the contents of the different subjects makes the research so broad that a large work team including specialists in the different areas would be necessary to address each required aspect. That is why educational research, which involves psycho-pedagogical and technological aspects, must be limited to a school grade, and focus on some topics of a subject, since each school grade has its own particularities, and the complexity of each subject must be considered. Given the scenario described in the previous paragraph, there is a need to regularize our level students in sixth grade of elementary education in the topics of ratio and proportion, which are contained in the axis number, algebra, and variation. Therefore, a tool was developed to support the sixth-grade student to approach the contents referred to ratio and proportion in a personalized way by means of one of the methods that is adaptive learning. A computer-based learning method was used to adapt the complexity of the contents to the needs of the users, according to a series of answers provided by them, thus contributing to the regularization of children in one of the subjects that is fundamental in Mathematics. In the case of Primary Education, which corresponds to the second step of Basic Education from 4th to 6th grades, the current curriculum (Secretaría de Educación Pública [SEP], 2017) contemplates in the academic formation of the student, seven subjects, of which Mathematics and Spanish are dedicated more hours in the school cycle (200 hrs.), taking both subjects every day of the week. For the study of the subject of Mathematics, it is organized in three thematic axes and 12 topics that are (SEP, 2019):

Number, algebra, and variation:

- Number,
- Addition and subtraction,
- Multiplication and division,
- Proportionality,
- Equations,
- Functions,
- Patterns, geometric figures, and equivalent expressions;

Shape, space, and measurement:

- Spatial location,
- Geometric figures and bodies,
- Magnitudes and measures;

Data analysis:

- Statistics,
- Probability.

The topics of ratios and proportions are in the first axis (number, algebra and variation) and become relevant since one of the purposes to be achieved is to identify and symbolize sets of quantities that vary proportionally, and to know how to calculate missing values and percentages in different contexts.

Given the scenario presented in the previous paragraphs, the problem posed in this paper is that elementary school teachers do not have enough time and relevant resources to work on the contents of the three thematic axes of the discipline of Mathematics with one of the methods of the personalized education approach, which is called adaptive learning. Breaking down the problem, a primary school teacher must cover 20 hours of work per week, four hours per day for five days, in which he/she must address the contents of the seven subjects of basic education, in addition to other subjects, corresponding to the personal and social development of the student, require time to make a didactic planning that allows him/her to prepare activities and select or build didactic materials, and then, for the work he/she develops, he/she uses more than the 20 hours per week covered by his/her salary. The material he develops and the exercises and problems he plans, in general, are for an average student, but it is required to adapt the contents to the cognitive level of the student, in addition to certain particularities that each student presents, which consumes a lot of time that is not available.

Therefore, this study developed an intelligent tool that helps sixth grade students by allowing them to have an adaptive learning in the topics of ratio and proportion, that is, a computer-based learning method is used that adapts the complexity of the contents to the needs of the users according to a series of answers provided by the users themselves.

Next, adaptive learning is discussed as a method that employs the personalized education approach.

Adaptive learning is a methodology that uses new technologies, specifically data analysis, to adapt education to the personal needs of each learner (Martin, Chen, Moore, & Westine, 2020). It involves adapting learning by analyzing the student's successes and mistakes to find out where improvements are needed. This learning method uses a computer system that collects data from all students. Based on this information, the application marks the activities to be carried out individually.

Theoretical Aspects

This section presents some studies that employ technology to support the teaching and learning processes of elementary school students.

Educational technology that supports e-learning has been developing two types of platforms: Learning Management Systems (LMSs) and Adaptive Hypermedia Systems (AHSs) aimed at education (Salas Rueda, 2024).

LMSs have functionalities that support the management of courses, users, groups, grades, etc., and allow content management.

AHSs are systems capable of recording student actions, interpreting them according to the associated user model and, consequently, adapting the learning process to the individual, i.e., personalizing learning. The diffusion and use of AHS in education are currently very limited, mainly for two reasons. One of them is that the software developed requires the teachers, who are the authors of the instructional design and activities, to devote great effort to use it. The other reason is that these systems need to have enough appropriate labeled contents, so that the system can organize them and automatically present them to the user based on the data it collects.

In a study conducted by Chávez Torres (2020), he used a tool called thematic portfolios, with emphasis on the implementation of adaptive learning technologies, to promote the resolution of mathematical problems and evaluate their impact on learning in a group of sixth grade elementary school students. The student loaded his answers into the system and could see which were correct and which were not, and when an answer was incorrect, he could review the procedure that led to the correct answer. This type of feedback was of great support so that students did not lose interest and gave continuity to their learning process. In the classroom, it can take a long time for the teacher to review several students and point out the errors to each of them, and in this case the software presents it immediately. It also showed the history of attempts of each exercise solved by the student, which is useful because it allows the teacher to present a more detailed report so that they are updated with the level of their students to give more attention to those who need it.

In another research Mancinas González and Montijo Mendoza (2021) describe how computational thinking is related to cognitive processes related to problem thinking, so it is proposed that in that study a mixed approach was developed and an exploratory scope shown as a case study design applied in a COVID-19 pandemic environment in the city of Hermosillo.

An application was designed to observe the types of computational thinking and the possibilities of adaptive learning in solving problems with fractions; in this application each teacher assigns an activity in the form of a test of fractions, with which an initial classification of the student is obtained.

A study by Roma (2021) shows a series of steps for the creation of digital teaching materials:

- They are accessible at any time and from anywhere, since they are online.
- They facilitate the students' tasks of searching and exploring information.
- They allow virtual representations in both figurative and three-dimensional scenarios.
- They provide highly motivating environments through gamified or playful learning approaches.

For the generation of new digital didactic materials, the following should be taken into account:

- A didactic material should have a sequence or narrative that gives sense and meaning to its pedagogical use.
- The digital didactic material should pose challenges and challenges to the students that involve the activation of intellectual processes.
- The DTM should also "excite" and not only activate the cognitive dimension of learning.
- The MDD must be interactive.
- The MDD must be multimedia in its forms of content presentation and interface.
- The MDD must provide a personalized management desktop for both the teacher and the individual learner.

Methodology

An application was built to support sixth grade elementary school students (11- and 12-year-old) in solving problems related to fractions and their operations, ratios, and proportions, following the methodology called METRICA in its Version 3 (V3). In this regard Portal de Administración Electrónica (PAE) (2021) points out that structured methodologies are based on the structuring and functional decomposition of problems into smaller interrelated units, which has several standards that support it, strengthening the confidence and effectiveness in it. Among the standards is ISO-9126, which states that any component of software quality can be described in terms of one or more of six basic characteristics, which are: functionality, reliability, usability, its characteristics that allow to deepen the evaluation of the quality of software products.

In METRICA V3, for each task, the participants involved, the input and output products, as well as the techniques and practices to be used to obtain them, are detailed. Similarly, this type of structured methodology is based on cascading life cycles, so in each iteration tests will be performed to describe the requirements necessary for that iteration, correcting the errors of the previous iteration, seeking to improve the system to its best version. METRICA V3 has a process-oriented approach, the order of the activities is not necessarily sequential, and it can be performed in parallel. The canonical structuring is composed of:

- Information Systems Planning (ISP).
- Information Systems Development (ISD).
- Information Systems Maintenance (ISM).

The application is considered a single system; the subsystems included in the tool are shown below:

- Login Management: subsystem in charge of users' mail and password validation.
- Registration Management: subsystem focused on the storage, edition or deletion of data entered in the student or teacher registry.
- Exercise Generation Management: subsystem focused on the selection of problems to be presented to the student.
- Follow-up Management: subsystem focused on the collection of results and procedures of the students, together with the presentation of these to the teachers.

For the development and use of the tool, two end users are taken into account:

- Student: who will fulfill the main objective of the tool by performing the activities to promote their skills; if necessary, the teacher will be notified directly for more direct attention.
- Teacher: who will make use of the tool through the stored results and procedures of the students, allowing him/her to have a more complete control of his/her students.

In order to delimit the characteristics of the tool and determine the functional (those describing the software operation) and non-functional (referring to emergent properties, such as, for example, storage capacity) requirements of the system, the data collection instruments described below were designed and applied:

First, a questionnaire addressed to the expert user (teachers) was conducted, which was oriented to the operation of the system and certain information requirements provided by the users; the questionnaire was designed in such a way that their answers were brief, concise, and precise for us to transform their answers into functionalities of the system.

Secondly, an open-ended questionnaire for sixth grade students, which consisted of questions focused on making our system more student-friendly, both in terms of design, typography and image. Considering that most children of that age are not yet able to handle very abstract concepts, we opted to make it more visual and interactive; as in the survey aimed at the expert user, transforming the student survey responses into system functionalities was slightly more abstract and interpretative.

The tool is a Web application hosted on a server with access to a structured relational database and as mentioned above, we will use a Model View Controller design pattern (with all the benefits it provides), so our definition will be as follows (Enriquez et al., 2023):

- Model: It is the central component of the pattern. It is the dynamic data structure of the application, independent of the user interface. It directly manages the data, logic, and rules of the application.
- View: Any representation of information, such as a graph, diagram, or table. Multiple views of the same information are possible, such as a bar chart for management and a tabular view for accountants.
- Controller: Accepts inputs and converts them into commands for the model or view.

In addition to dividing the application into these components, the Model-View-Controller design defines the interactions between them.

1. The model is responsible for managing the application's data. It receives user input from the controller.

2. The view makes the presentation of the model in a given format.

3. The controller responds to user input and performs interactions on the objects in the data model. The controller receives the input, optionally validates it, and then passes the input to the model.

The system architecture described above is shown in Figure 1:

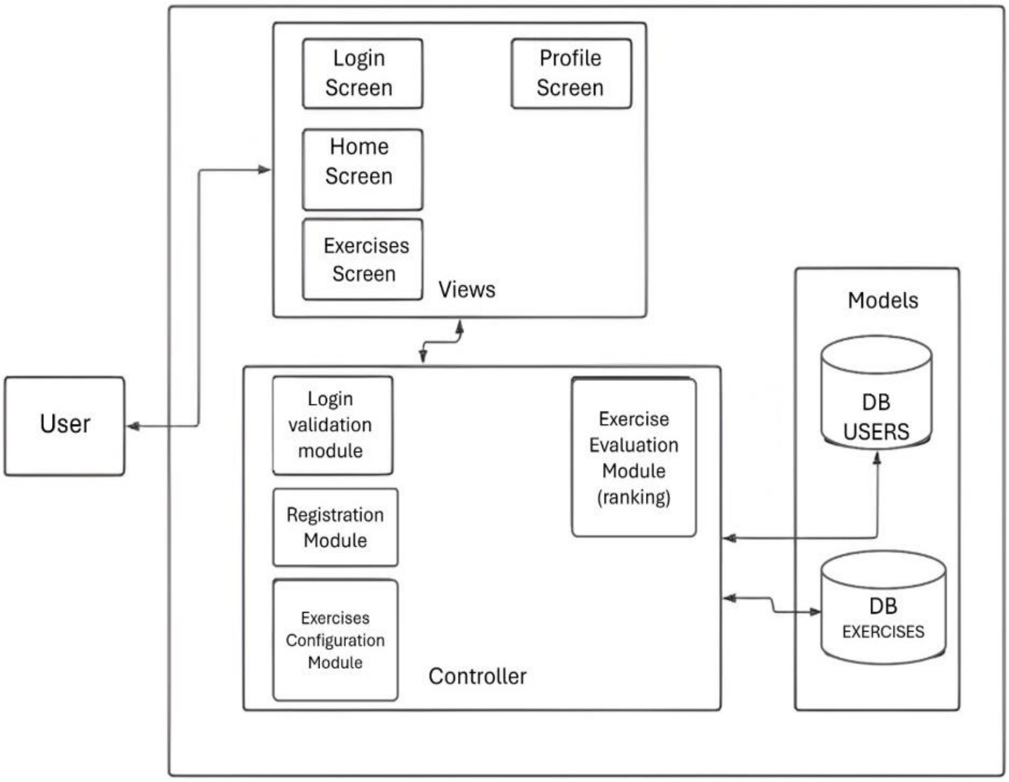


Figure 1. System architecture.

Based on the system architecture in conjunction to the subsystems, we will delve into the Student Level Generation Management system. For this subsystem an artificial intelligence model was developed, specifically a decision tree; for this process an artificial dataset was developed to classify the students and train the model by supervised training.

The dataset consists of 100,000 rows and nine columns alluding to the nine problems presented in the diagnostic test; each row represents a student who has answered the diagnostic test, and each column has random values of 0 or 1, where 0 is incorrect problem and 1 is correct problem; for the classification of each row a specialist in the subject was consulted, who was presented with various combinations. Based on the classification made, the decision tree was trained.

The diagnostic questionnaire solved by the student upon entering the system included nine activities which are divided into three: The first three review the development of the student's quantitative proportional thinking, the next three the transition to quantitative thinking, and the last three the development of quantitative thinking, which is when the student uses tables to establish ratios and proportions, as well as when using the rule of three.

Proposal of Activities (Design of the Proposed Activities)

Once we have an architecture of the system, we must complete it with activities both for the diagnostic questionnaire and for the student to solve exercises and problems. Next, we will show the division that was handled in the activities and for each one of them an example.

Reduction and enlargement of figures (by means of the idea of the photocopier or the drawing to scale) work the idea of proportion (qualitative proportional thinking).

The similarity of figures allows us to make representations of real objects at a larger (enlargements) or smaller (reductions) size (Piaget, 1978). In this case we can follow dynamics in which a story is followed by a story, a story of reduction or enlargement of the same figure, such as goldilocks and the three bears; an example of this type of activity is shown in Figures 2 to 4. Figure 2 shows the image of a bed, which is the original and the student is asked to select the reduced bed from eight images of beds that are shown, but only one is the reduced one since the remaining seven do not keep the same structure, because the backs of the beds are different, or the measures are not reduced proportionally.

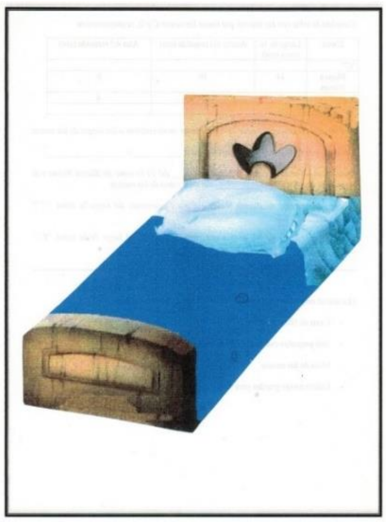


Figure 2. Image of the original bed.

Figure 3. Beds reduced, but not proportionally.

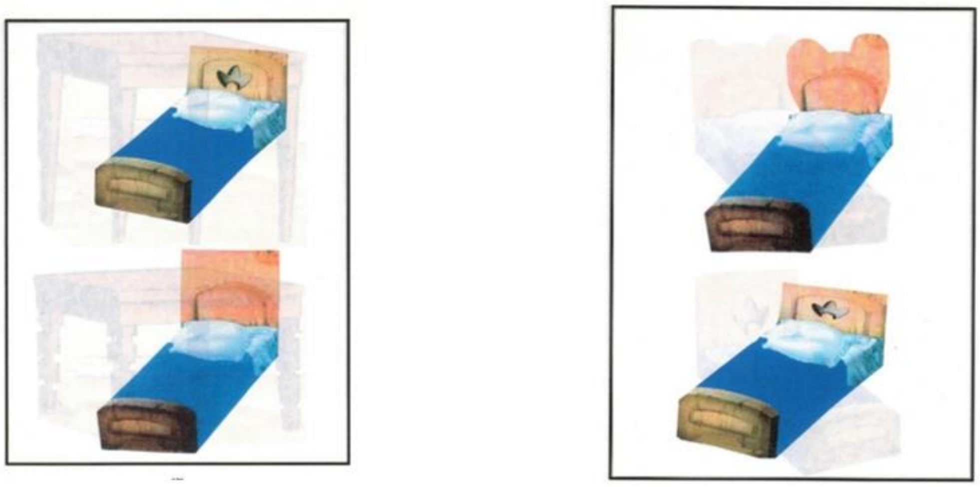


Figure 4. Only one of the beds is reduced proportionately.

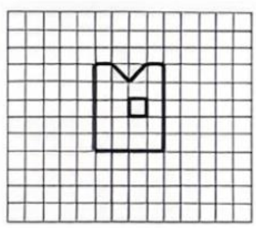
In the representations of objects, the similarity ratio is called scalar factor.

For the primary grade we are dealing with, we solve problems of reduction and enlargement of geometric figures in the Cartesian plane, since students need the necessary guidance to demonstrate as learners their abilities and knowledge in the face of different problems of their social eternity (Ruiz & Valdemoros, 2002).

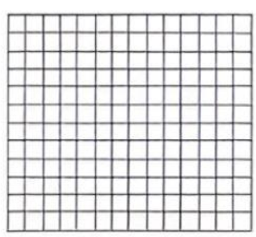
Use of the Grid

It is important that the next step in the development of the student's skills in this thematic axis is to develop the ability to use the grid, which is used to count squares when making drawings that are proportional to each other; for this the outline of the images or the sides of them must have the number of squares that correspond to the requested reduction or enlargement. For example, if the image of the vest is four squares wide and five squares long and the vest is requested to be enlarged twice, then it will be 12 squares wide and 15 squares long (transit from qualitative to quantitative proportional thinking). The problems proposed for this step are shown below (Figure 5).

Ms. Saucedo knits vests and has been asked to knit one as an extension of the next one.



In this space below, draw the new vest, doubling each side of the sample vest.



Next, write down the steps you followed to draw it.

Figure 5. Diagnostic questionnaire activity.

Expressing Reasons Using Verbal Categories

In the student's academic development, it is important to become familiar with the vocabulary related to ratio and proportion, half, quarter, double, third; this helps the student become more familiar with the notation he/she will be learning and to see it in a more natural way. The exercises in this phase are related to those solved using the grid.

Formulating Questions

This step seeks that the student knows in which situations he must use the ratio and proportion to find a solution to a problem; with this purpose several statements are presented that at first sight can be simple, but the way of abstraction of the data for the students is different if the concept of ratio and proportion has not been handled, since studies have verified that most of the students see that a/b as isolated numbers, without any relation between them.

Filling in Tables and Working With Both Internal and External Ratios

The next step involves the conception of the existence of a progression in ratios for which visualization in a table is useful (Figure 6).

Work in pairs to solve this problem.

The school's walking team covers a 4 km circuit.

The teacher is recording in a table like the one below the laps and kilometers completed by each member of the team. Analyze the table and complete it.

Name	Rosa	Juan	Alma	Pedro	Viktor	Silvio	Eric	Irma	Adriana	Luis	María
Laps	1	2	5	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	0.75	1.25	1.3	2.6
km											

Figure 6. An example containing tables to represent ratios.

The proportional distributions are traditionally worked in the classroom through situations referring to the distribution of inheritances, cash, and profits in commercial companies. This form of work generally follows the process of teaching the theories, theorems, concepts, and formulas that allow making proportional distributions with numbers, and then situations such as those previously mentioned are proposed so that students can directly apply what they have been taught. In this sense, the resolution strategy used by the students will be the one institutionalized by the teacher, which will be applied mechanically (Ruiz, Chavarría, & Rodríguez, 2024).

Results

This section shows the system interfaces, and the tests carried out with a group of 30 students of 6th grade of Primary Education.

Definition of User Interfaces

Below are some screenshots of the graphical interface of the application.

When opening the application for the first time, the registration screen will be displayed, where the student must provide a username and password. He/she will then be able to log in by entering both data, as shown in the Figure 7.

Once the student enters the system, he/she will be able to choose an avatar and must answer a diagnostic questionnaire so that he/she can have a level and according to this the system will provide exercises and activities according to the level of knowledge that has been diagnosed. Figure 8 shows the avatars that can be chosen. Once having worked through the activities, you can advance to the next level of difficulty.

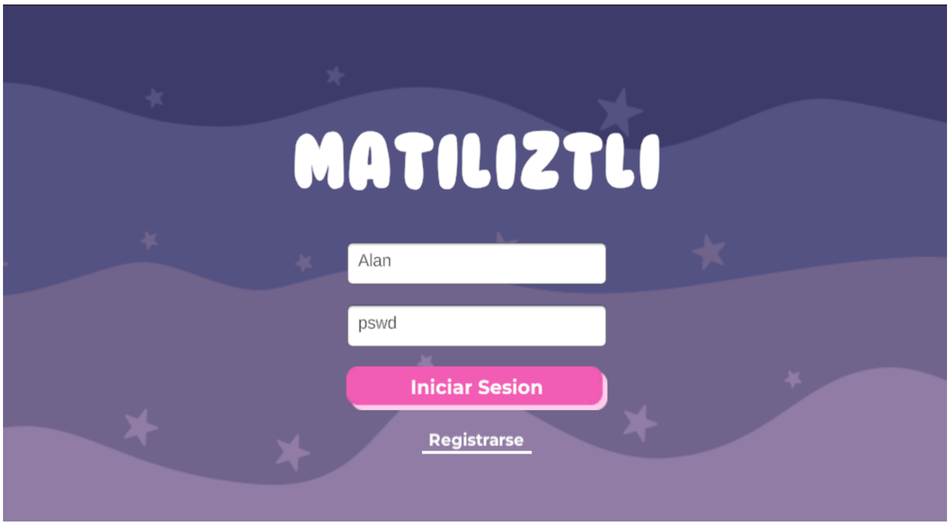


Figure 7. Login interface.

Figure 8. Avatar selection interface.

Figure 9 shows one of the activities presented as a game called *Carreritas*; here the student must perform operations between fractions as well as compare between the fractions presented to decide if it is greater than, less than, or equal. To do this, the student advances on a lane and must choose the one that contains the correct answer.

In the same Figure 9, there is a game called *Chocolatoso*, where the student must find the fraction equivalent to the given one using the parts of a chocolate. The chocolate looks like squares, and the student can count them as if they were on a grid. Also in Figure 9 is the image of the game *Esp ŕitus chocarreros*, which consists of trying to keep the spirits from reaching the center of the screen; to keep them away, the student must solve questions that appear on the screen, referring to proportions.

Figure 9. Game selection interface.

After the system was completed, it was tested with a group of 30 students in 6th grade to check that it was working correctly.

Regarding the diagnostic questionnaire that the 30 students completed, it was found that 60% of them correctly solved the activities corresponding to the transition from qualitative to quantitative proportional thinking, since they adequately constructed the figures requested in the grid, but they did not manage to correctly solve the activities referring to the use of the rule of three and the filling in of the tables. Eighty percent correctly solved the exercises of selecting the image that was reduced or enlarged with respect to the model presented. 20% did not manage to correctly draw the figures requested in the grid; nor were they successful in the tasks of filling in the tables and using the rule of three.

Once the questionnaire was completed and according to the level detected by the system, the system provided each child with activities that were in accordance with the level obtained.

Discussion

Not as many students have been able to develop their qualitative thinking, which coincides with Ruiz & Valdemoros (2002), this was observed in the diagnostic questionnaire because there were students who considered that when reducing a figure proportionally, it was enough to make it smaller by subtracting any quantity from a single side of the figure. As they worked with the activities proposed in the system, the children understood that if a figure is reduced or enlarged proportionally, then all the sides that form the figure must be multiplied by a factor, which is called the scalar factor. What helped them a lot was to complete figures on a grid, as well as to use expressions such as half, third, double, quadruple and to be able to represent them numerically. To introduce equivalent fractions, it was illustrated with the cutting of chocolate bars, for example, to represent, a chocolate was cut into two equal parts and from there a half was selected. A second bar of chocolate was divided into 4/4, from which 2 were selected and the student could observe that a half was the same as two quarters.

Conclusions

The use of technology to support the student's learning process is required if the digital material used has been supervised by the teacher and is at the cognitive level of the student. Digital educational resources have become a useful tool for both the teacher and the student, since the groups with which a teacher works are heterogeneous, i.e., they have students with different learning styles, as well as different cognitive level and different study habits, which means that the teacher cannot attend to each student as required, so if there is a system that contains material that adapts to the particularities of the student, then the work done by the teacher in the classroom can be complemented with what the student can work on the system.

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