

# DIGITAL SIMULATION USED TO EVALUATE SELF-LEARNING APPLICATIONS AND ITS USERS

José Maclovio Sautto Vallejo<sup>1</sup>, Universidad Autónoma de Guerrero

## ABSTRACT

The paper's main objective consists on exposing a methodology to evaluate the process of learning in a Self-Learning System named MATE1. The methodology also allows us to evaluate the system's different components, and the long-term goal is to understand the learning processes. This proposal consists on the design, construction and feeding of a database that allows to reproduce the activity deployed by the user on the system and to evaluate the application's effectiveness. It facilitates to capture the users' activities and to reproduce these activities in a matter of seconds, fixing our attention in those aspects that we consider important for the evaluation of the learning process. The numeric values collected by this database may be used, in the future, to test diverse approaches in the search of patterns that may characterize the learning process.

**Key words:** Digital simulation, Systems evaluation, Learning evaluation, Self-Learning Systems.

MSC: 97C80.

## RESUMEN

El objetivo principal de este artículo consiste en exponer una metodología para evaluar el proceso de aprendizaje de estudiantes en un sistema de autoaprendizaje llamado MATE1. La metodología también permite evaluar las distintas componentes que conforman el sistema, el fin último es entender los procesos de aprendizaje. La propuesta consiste en el diseño, construcción y alimentación de una base de datos que permita reproducir la actividad desplegada por el usuario en el sistema y evaluar la efectividad de la aplicación. Esto permite reproducir la actividad desplegada por el usuario durante meses en cuestión de segundos y fijar nuestra atención en aquellos puntos que consideremos importantes para la evaluación del proceso de aprendizaje. En el futuro, los vectores característicos generados por la base de datos bajo la aplicación de distintos criterios permitirán identificar patrones de aprendizaje que caractericen este tipo de procesos.

## 1. INTRODUCTION

A self-learning system (SLS) is based on the idea that the user-system interaction brings the user the possibility to dominate some specific topics, fact which we call *learning*.

The evaluation modulus objective in the SLS is, besides the student's learning evaluation, the evaluation of the SLS effectiveness; its long-term objectives are to improve the knowledge related with how learning is reached in this type of systems and to create mathematical models of this process by establishing approaches or methods for the pattern's generation.

The methodology consists on collecting data generated by the user-system interaction, in order to be able to reproduce the user's activity. With the process' logical model (system - user), we will be able to perform the necessary adjustments to understand the process and to transform this database into characteristic vectors which, in the future, will allows us to advance in patterns classification, and in separating the space in disjoints regions (the desirable thing) or diffusely disjoints regions (with the use of fuzzy sets). To associate each region with desirable behaviors that we can modify or stimulate, involves a multidisciplinary, permanent and systematic work in this field. Figure 1 illustrates the proposal. Basic concepts will be introduced in the next section.

---

E-mail: <sup>1</sup>sautto@msn.com

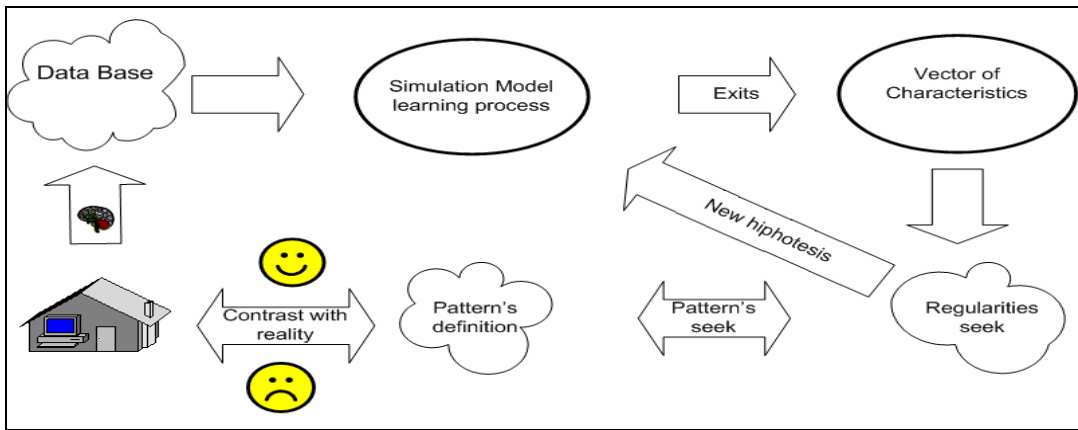


Figure 1.

## 2. SYSTEM: MATE1<sup>1</sup>

The system was designed according to the provisions and main objectives included in the Mexican plans and programs of study for the first grade of basic education. Such objectives were turned into learning objects<sup>2</sup> (L.O.). The system is conformed by a main menu and 6 submenus, each one of which has diverse activities or lessons. These activities consist of exercises randomly generated, automatically evaluated: when the answer is wrong, the system presents the right answer. The system's access is easy, so that a student can enter and to navigate in it in a simple way and without adult's supervision.

### 2.1. Content Organization

The learning objects were developed in six units, each one corresponding to one of the different submenus that conforms the system and according to the evaluation process proposed by the Secretary of Public Education (SEP) of Mexico. Such organization is shown in the following table:

Table 1. System's content by themes.

Theme	Sub theme	Unit
Decimal Numeric System	00 To Count	1,2,3
	01 Successions	1,2,3,4,5,6
	... ..	.....
...	...	.....
The clock	16 The clock	4,5,6

A L.O. presented in different units differs only in its level. For example: sub theme to *count* includes activities with groups from one to five items in the first unit, groups from one to eight items in the second unit, and groups from zero to nine items in the third unit.

Each lesson is associated to a *Learning Object*, which is constituted of:

- Ide: unique number that identifies each learning object.
- Name: short name used to identify the object.
- Description: observable and clearly specified behaviors associated to the object.
- Learning indicators: approaches to accept or to reject the fact that the learning object has been reached.
- Learning object status: boolean indicator with value of 1 when the learning indicators have been covered satisfactorily and value of 0 otherwise. The learning object status has a meaning only when it is incorporated to an individual's (user's) learning status.

<sup>1</sup>Maclovio Sautto Vallejo (2003). *Mate1: User's Manual*. (<http://galeana.uagfm.mx/~sautto>)

<sup>2</sup>Learning Object is defined here as any entity, digital or non-digital, which can be used, re-used or referenced during technology supported learning. Ref: Instructional **Management** System Global Learning Consortium Inc. (IMS, 2004), Learning Technology Standards Committee (IEEE, 2004), Information Technology for Learning, Education and Training (ISO, 2004) y Advanced Distributed Learning The Sharable Content Object Reference Model (ADL-SCORM, 2004).

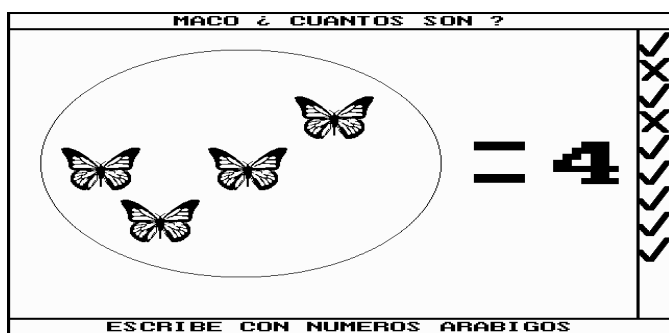
- Weight: quantifier of the relative difference between the evaluation of the learning and a learning object with regard to other objects.

**Table 2.** Example for the learning objects definition.

Id	Name	Description	Learning indicators	Weight
1001	Contar2	To count collections from one to eight objects	At least 0 from the last 10 exercises are correctly solved	1

## 2.2. Description

The system generates exercises at random to each learning object, and each learning object is associated to a lesson in the system. In Figure 2, a certain amount of items appear inside an ellipse, and the system asks the user to write down the number of items. The quantity requested in all of these cases is a single digit (from 0 to 9). Once written, the system analyzes the number: if it is right, it shows a mark in the right margin of the screen; if the answer is wrong, the system rejects it up to two times; if the error persists, an error mark is showed in the right margin and the system presents the right answer at the same time.



**Figure 2.** Lesson: To count.

## 3. DATABASE DESIGN

The database associated to the system has two basic purposes: the former is to show at any moment the user's learning (according to an approach), and the latter is to be able to reproduce the activity developed by the user in the system.

To know the user's learning, the system generates a Learning Status Matrix. The matrix associates each L.O. with a four field vector: the first three fields show a synthesis of the activity deployed by the user, the last field is the final evaluation of the item according to the defined criteria (i.e. if the user has or hasn't reached the L.O.). Table 3 shows the fields and its description.

**Table 3.** The *Learning Vector* is described as follows.

Field	Description
Good	It indicates the number of times that the exercises associated to the learning object have been answered correctly
Bad	It indicates the number of times that the exercises associated to the learning object have been answered incorrectly
Last	It indicates the number of exercises that have been answered correctly without any mistake
State	0 = The user doesn't domain the learning object. 1 = The user domain the learning Object

**Note:** the value for all these fields is zero at the beginning of the learning process.

The learning vector is modified each time the user answers an exercise, if correctly, the fields "good" and "last" are increased in one; otherwise (i.e. a mistake), increases in one the field "bad", and "last" becomes zero. Each time the user accesses the system, it automatically opens, reads and begins to modify the matrix associated to that specific user. This matrix is important to know the learning achieved by the user. Mate1 generates -at request- a list with the information contained in this matrix.

To reproduce the activity deployed by the user in the system, each L.O. has a specific type of exercises related to it. Such structure containing all the formats is defined as a seven-integer array (gen), so each time the system generates an exercise, it also liberates a gen that stores information; and allow us to reproduce the exercise and the answer given by the user.

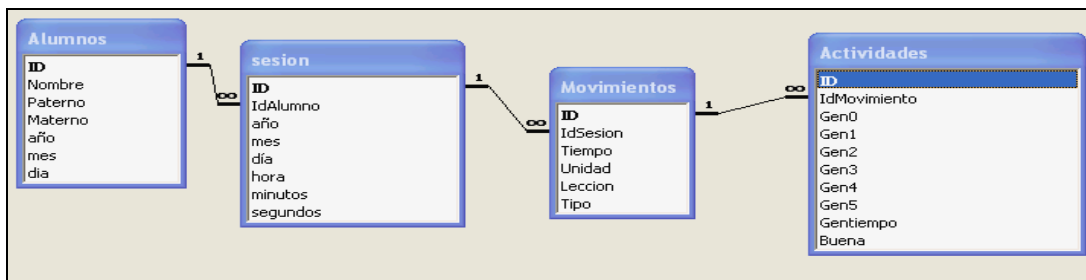
Table 4 describes the meaning of each field for the gen associated to the learning object "to count".

**Table 4.** Description of the gen "to count".

Learning objects	Description
Contar1, Contar2, Contar3	P0: It asks the number of objects showed on screen P1: Attempt 1 (answer given by the user) P2: Attempt 2 P3: Attempt 3 P4: It is not used. P5: Number of objects showed on screen P6: Answer Time

#### 4. DATABASE DESCRIPTION

To access the system, the user's name has to be included in a table named "students"; the registration number is assigned to the user as a password and it allows us to store each user's information separately. When the user identified as a "student" accesses the system, date and hour of access are saved in a table named "sessions". The unit and lesson chosen by the student are also stored in the table "movements", as well as the time used to select the lesson. A gen is stored in the table "activities" each time an exercise is performed by the user in the selected lesson. The database structure, which allows us to generate learning patterns, is shown in Figure 2.



**Figure 2.** Relationships diagram.

With this database, and by changing the learning approaches in the L.O., we are able to rebuild the evolution of the learning matrix. When a change in the learning status takes place, a new node will be added to the **Learning Trajectory**, which is defined as the succession  $ta = (a_1, t_1) \rightarrow (a_2, t_2) \rightarrow \dots \rightarrow (a_p, t_n)$ , where  $a_i$  is the ide associated to a L.O. whose state value has changed, and  $t_i$  is the time in which the change has taken place.

#### 5. EVALUATION OF BASIC GROUPS

This is the first aggregation level for the L.O., and it's made by applying one or more approaches (thematic or temporal, generally). From the mathematical point of view, they are L.O.'s groups that form the group of all the L.O.

The last one, defines an entity to evaluate named *Objective of Learning* (OL), constituted of:

- Ide. Unique number that identifies each OL.
- Name: Short name to identify the OL.
- List of L.O.
- Weight: Quantifier of relative difference related to others OL.

Example: Under the time criteria, we can group the L.O. in units. Within our application, there are 6 units, and therefore 6 OL. Table 5 shows the time approach for OL grouping. Table 6 shows other grouping criteria (by themes).

**Table 5.** Time criteria grouping.

Id	Name	List of L.O.	Weight
002	U02	Contar02; Sucesiones02; Comparar02; Escritura02; Suma02; Sumavertical01; Resta02	1

**Table 6.** Another possible grouping, based on the thematic criteria.

Id	Name	List of L.O.	Weight
002	Arithmetic operations	Suma01; Suma02; Suma03; Suma04; Suma05; Suma06; Suma07; Resta01; Resta02; Resta03; Resta04; Resta05; Resta06	0.3

From the mathematical point of view, the *Basic Group* is a partition of the universe defined by the L.O. It means:

- The intersection of two OL belonging to one basic group is empty. This guarantees that any L.O. won't be considered twice in an evaluation.
- The union of all the OL belonging to one basic group is the universe, it guarantees that all the L.O. are considered in the evaluation.

For the Evaluation of Learning, we define:

**State of knowledge**  $C(x,t)$ : it is a Boolean vector, where each one of its components corresponds to a L.O. status. The state of knowledge is associated to a specific user ( $x$ ) at one given time ( $t$ ).

$C(x,t)$ , where:  $x$  = User to be evaluated,  $t$  = Time of observation.

**Measure of the State of Knowledge**  $M(C(x,t))$ : it is a function defined in the space of states of knowledge. The range of this function is the interval  $[0,1]$ . Formalizing: if  $\wp(t) = \{C(x,t) | x \in X \wedge t \in R\}$  where  $X$  is the group of the students to evaluate and  $t$  the time in which the measurement is done. Then  $M(C(x,t)): \wp(t) \rightarrow [0,1] \subset R$ .

Supposing that all the L.O. have the same weight, the evaluation is defined by:

$$M(C(x,t)) = \sum_{i=1}^n c(i) / n .$$

Where  $c(i)$  is the  $i$  component of the student's learning vector and  $c$  is a Boolean vector of component  $n$ . So, the maximum value of  $M$  is one and the minimum is zero.

The **Learning Speed Trajectory** is associated to the function that evaluates learning. It is the succession:

$$tr_a = (M(C(x,t_1), t_1) \rightarrow (M(C(x,t_2), t_2) \rightarrow \dots \rightarrow (M(C(x,t_n), t_n).$$

## 6. EXPERIMENTATION

The system and the program were tested in two elementary schools in the port of Acapulco, Guerrero, Mexico, with the participation of 117 pupils. Only 47 from these interacted with the system during 90 or more minutes (real time). An exploratory analysis was made with such 47 pupils. The obtained database was used to feed a logical model of the process that allows the modification of the evaluation criteria. For each evaluation criteria it can be made a:

- Group analysis of learning.
- Individual's learning speed trajectories identification.
- Statistical analysis about the influence of the drawings (used by the system) on the learning process.

## Group Analysis of Learning

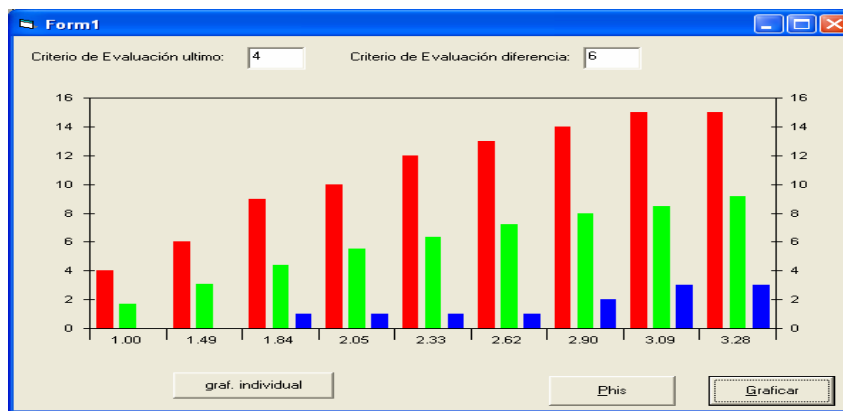
The analysis was made as follows:

1. The learning approaches were settled down (the value of “good”, and the difference between “good” and “bad”, used to confirm that the user has really learned). For each couple of values, a different result is obtained.
2. 10 minutes intervals were taken to determine the number of L.O. that each student had learned (according to the parameters of the previous paragraph). For each interval, we calculated the maximum value, the minimum, the average and the standard deviation. Then a graph was elaborated with the first three values (max, min. and average). The value for the deviation was indicated at the base of each interval.
3. Four regions -or classification values- were determined with the average and the standard deviation.
4. Finally, a table was made to allocate each student in a region (Table 7).

**Table 7.** Allocation criteria in each interval of time.

Region	Criteria (X number of lessons)	Interpretation
1	$X \leq \mu - \sigma$	The student is in the worst region: one standard deviation under the average or more.
2	$\mu - \sigma < X \leq \mu$	The student is located under the average up to the standard deviation.
3	$\mu < X \leq \mu + \sigma$	The student is above the average for less than a standard deviation.
4	$X > \mu + \sigma$	The student is above the average for more than a standard deviation.

As it is shown in Figure 3, when testing different evaluation criteria, there is a relation between exposition to the system and the increasing of the standard deviation; it means: as the interaction time with the system is increasing, the range determined by Max and Min becomes more and more wide. This conclusion is valid for any evaluation criteria.



**Figure 3.** Graph (Max, Mean, Min) of LO vs. time.

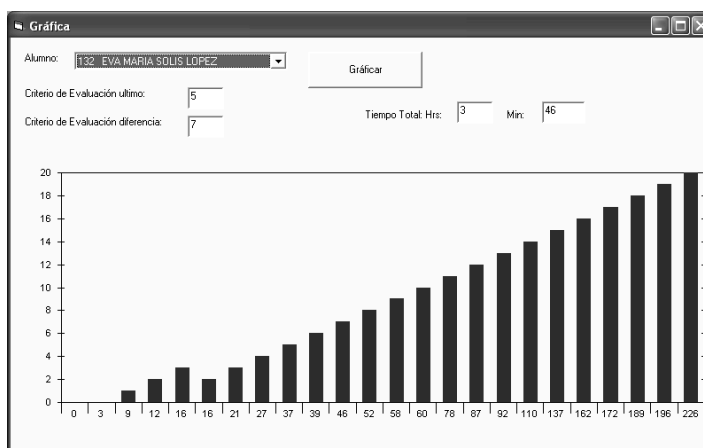
Table 8 shows the time interval and the region associated to each student. These values were used to create the graph in Figure 3.

**Table 8.** Allocation of students in each time interval.

Alum	10	20	30	40	50	60	70	80	90
70	2	2	2	3	3	3	3	3	3
80	1	1	1	1	1	1	2	1	2
89	3	4	4	4	4	4	4	4	4
90	2	2	2	2	3	2	3	3	2
95	2	1	1	1	1	1	1	1	1

Alum	10	20	30	40	50	60	70	80	90
132	2	2	2	3	3	3	3	3	3
140	2	1	1	1	1	1	1	1	1
145	4	3	2	3	3	3	3	3	3
146	3	3	3	3	2	2	2	2	2
149	3	3	3	4	4	4	4	4	4

**Learning Speed Trajectories.** The system allows us to modify the evaluation criteria and to select a student from the database. Figure 4 indicates the time in which the student reached the L.O. It also indicates the total time of interaction user-system. The vertical axis corresponds to the number of L.O. reached by the student.



**Figure 4.** Individual graph of total L.O. vs. time.

Table 9 shows the learning trajectory: the L.O. reached by the student, the time when it happened, as well as the number of L.O. reached by the student and used to build the learning speed graph. (Columns 1, 2, 3, and 4, respectively).

**Table 9.** Learning trajectory & learning speed.

Unit	Lesson	Time	L.O. No.	Unit	Lesson	Time	L.O. No.
2	0	9	1	2	5	60	10
2	6	12	2	1	0	78	11
4	9	16	3	5	6	87	12
4	9	16	2	5	2	92	13
1	1	21	3	6	8	110	14

**Note:** that the student begun his learning in unit 2, then “jumped” to unit 4 and later, to unit one. It is necessary to perform a deeper analysis about this fact.

### Statistical analysis about the influence of the drawings on the learning process.

As it was said, the program was tested with the participation of 117 children, who performed a total of 12,965 exercises.

In the system Mate1, the topic *to count* is developed in three lessons, each one introduce a 10 exercises series for which the system randomly selects one of 11 drawings. Later, according to the unit, a random number is generated inside the established level for the lesson. Finally, the selected drawings are presented on screen asking the user to write the corresponding number.

**Table 10.** Number associated to each drawing in the system.

Number	Drawing	Number	Drawing	Number	Drawing	Number	Drawing
1	Bear	2	Kangaroo	3	Lobster	4	Butterfly
5	Train	6	Fly	7	Horse	8	Mouse
9	Dog	10	Cow	11	Deer		

Clearly, it is referred to two dichotomy variables for which the statistical test phi was used as it is described in the following example:

Let us suppose that the drawing to analyze is "BEAR", a table is created as shown below:

**Table 11.** Phi analysis for “bear”.

(X)			
Y(Bear)	Right	Error	Total
Choice	(A) 1,223	(B) 82	1305
No choice	(C) 10,832	(D) 828	11,660
Total	12,055	910	12,965

$$\phi = (AD - BC) / \sqrt{(A + B)(C + D)(A + C)(B + D)}$$

It means that the quotient of the coefficient Phi is the difference among the proportion of successes using the analyzed drawing and the rest of the drawings and the values will be between +1 and -1. When this proportion is the same, the quotient is zero, if the draws affects positively, the Phi value will be near +1, if negatively, it will be near -1, when it is near to zero, it doesn't affect. For the last example, table 11 shows that -from 12,965 exercises- 1,305 exercises had the "Bear" drawing. The answer given by the student when the "Bear" drawing appeared was right in 1,223 occasions and wrong in 82 occasions. From 10,832 exercises with different figures, 11,660 were answered correctly and 828, erroneously.

**Table 12.** Phi value for the different drawings.

Drawing	1	2	3	4	...	8	9	10	11
Phi	0.0096	0.0171	-0.011	-0.009	...	0.001	-0.007	0.003	-0.017

From the Table 12, it is possible to conclude that the drawings don't affect learning. A more comprehensive analysis was made considering each student and the impact of the use of these drawings on his learning.

## 7. CONCLUSIONS

The database reported here, and its logical model, allows:

- To reproduce the user's activity in the system.
- To reproduce the learning process.
- To define when a module requires maintenance or modification.
- To modify the learning criteria and to know the impact of any modification in the logical model.

## REFERENCES

- SAUTTO VALLEJO, M. (2003): **Manual de usuario de Mate1**. <http://galeana.uagfm.mx/~sautto>
- EEE LTSC (2003): **Learning Technology Standards Committee 21/04**. (<http://ltsc.ieee.org>)
- IMS (2004): **Instructional Management System Global Learning Consortium Inc. 21/03**. (<http://www.imsproject.org/>)
- ISO/IEC JTC1/SC36 (2004): **Information Technology for Learning, Education and Training** (<http://jtc1sc36.org>) 21/03.
- BISHOP (1980): **Discrete Multivariate Analysis**. The MIT Press, 6<sup>th</sup> edition.