The Use of MARIE CPU Simulator in the Computer Architecture Course: A Brief Exploratory Study of the Students' Perception of Learning

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Abstract
It seems that the combination of teaching practices creates interesting results in several areas of knowledge. The teacher has to always bear in mind that he/she has to present educational contents regarding his discipline always trying to present it an attractive way through new teaching dynamics. The challenge is to not to distance from the curricular content by using a broader educational proposal, intensifying the interaction with the students with the problems related to the professional area with artifacts and tools. Under such circumstances, the computer simulation can be a valuable teaching tool for the necessary contents in the formation of students. Through exploratory research it is possible to exemplify the strategy of using a simulator in the presentation of specific content, in the case presented here the introductory study of the operation of the CPU and data bus in the architecture of a hypothetical processor. The data collection instrument, in relation to the student´s perception of their learning experience interrelating the theoretical part with the simulator seeking to capture a first impact on the use of the simulator. The quantitative and qualitative data present in the questionnaires were processed using IBM SPSS® software. The analysis conducted through descriptive statistics, standard measures of dispersion and percentiles, absolute and relative frequency and Spearman correlation coefficient. The teacher activity in the classroom changes considerably, in the sense of not requiring the various repetitions of the concepts involved that usually occur, requiring an assistance that seeks to facilitate the use of the simulator.

Keywords: cpu simulator, teaching tools, pedagogical practices

Introduction

This study aims to present a strategy for teaching Processors and Assembly Language for students of Computer Science, Information Systems and Technology in Analysis and Systems Development, and the students' perception of learning in the Computer Architecture discipline. Through exploratory research it is possible to exemplify the strategy of using a simulator in the presentation of specific content, in the case presented here the introductory study of the operation of the CPU and data bus in the architecture of a hypothetical processor.

It can be said that the simulation proposed in this study can be used as a support to the communication channel between the teacher and the student (JOCHEMS; VAN MERRIËNBOER; KOPER 2003). Considering as a support a virtual environment with specific format that is used to present and display a content. Thus, the simulation works as a media that communicates its content in one or more ways (NUNES, GAIBLE 2002).

Simulations

Computer simulation environments have the potential to engage students in a learning experience that enables a deep understanding, as opposed to surface learning, which only requires memorization. It can be noted that an active participation and involvement in discussions, student-student or teacher-student, are required to perform a simulation.

Simulation is a form of experiential learning. Simulations consist of teaching scenarios, where the student is placed in a world defined by the teacher. It represents a reality within which students interact. The teacher controls the parameters of this world and uses it to achieve the desired teaching results. Simulations serve as laboratory experiments where the students themselves are the test subjects. They experience the reality of the scenario and gain knowledge from it.

Simulations can be performed in different ways. The main element is the content of its context. Students must make decisions within their context. Success is often determined by the engagement of the participant. The goal is to acquire knowledge and understanding, developing critical thinking.

Purposes of CPU Simulation

The study of the main functions of the Central Processing Unit (CPU) in the disciplines of Computer Architecture and Organization, always poses a challenge to the understanding of students to the extent that it gathers new knowledge combined with a data processing dynamics in the machine level.

Basic Operations and Operation of the Processor

The study of Processors is essential in the disciplines of Computer Architecture and Organization, allowing the understanding of the interrelationship between hardware and software.

One possible strategy for presenting the initial concepts of operation of processors and their programming in machine language is the presentation of a simplified processor as a hypothetical machine (STALLINGS 2013) where it is possible to introduce, with reduced complexity, the concepts regarding the use of basic registers such as: accumulator, program counter, instruction register, in addition to addressing memory access, the use of buses and input and output devices. Therefore, by using this idea of simple processor the Computer Architecture and Organization books intend to introduce concepts that are basic to the understanding of any processor, such as CPU (Central Processing Unit), ALU (Arithmetic Logic Unit) and registers.

The strategy applied in the computer courses where the simulator was used consisted of an analytical presentation of a hypothetical machine with 16-bit instructions, divided into 4-bit operation code and 12-bit address to which each instruction refers. This machine was then studied analytically and the CPU simulator was introduced afterwards to strengthen and deepen the students' knowledge.

MARIE CPU Simulator

The simulator MARIE (**M**achine **A**rchitecture that is **R**eally **I**ntuitive and **E**asy) (NULL, LOBUR 2010) is a graphical learning environment that didactically presents the operation of the architecture of a hypothetical machine. In this environment the students are able to: create and edit programs in Assembly language; assemble source code in machine code; run the machine-code programs developed; and observe and debug their programs using various tools provided within the simulator. The screen of MARIESim environment is shown below in Figure 1:

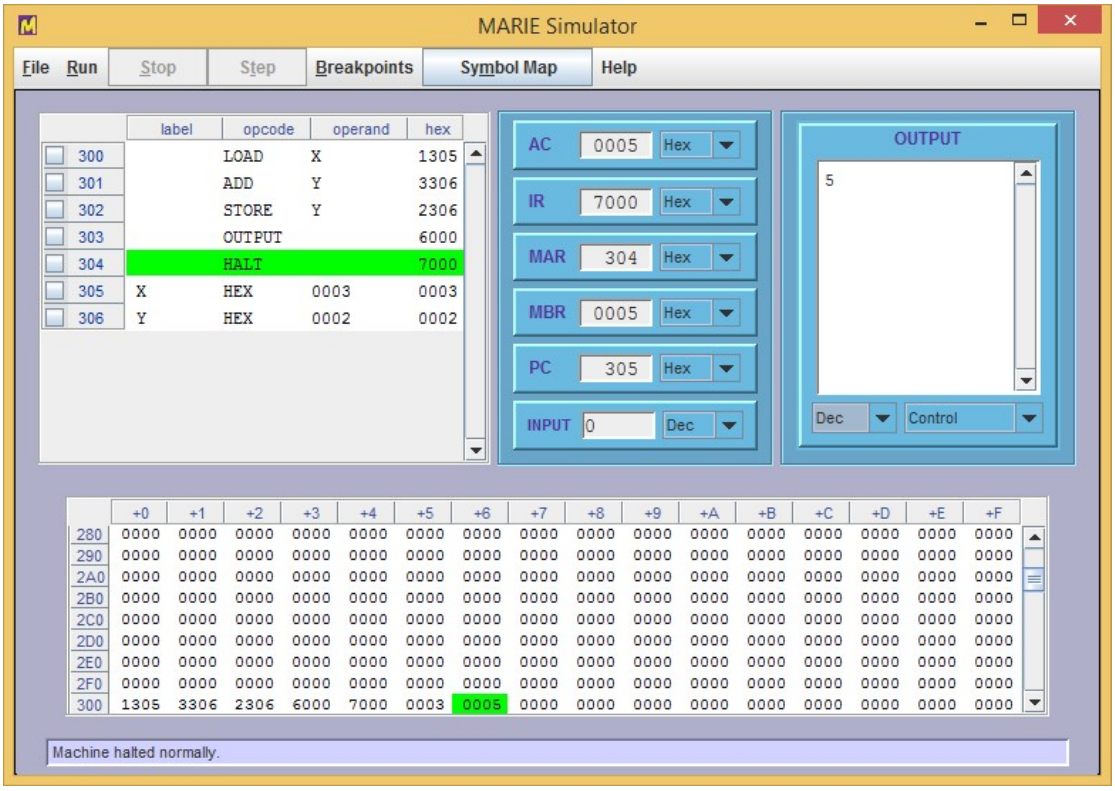

Figure 1: MARIESim Environment Source: NULL; LOBUR 2010

The simulator also offers the option of using the path simulator environment that data roam when the instructions are run by the processor of the hypothetical machine under study, in this case, MARIEDataPath. Figure 2 shows this environment.

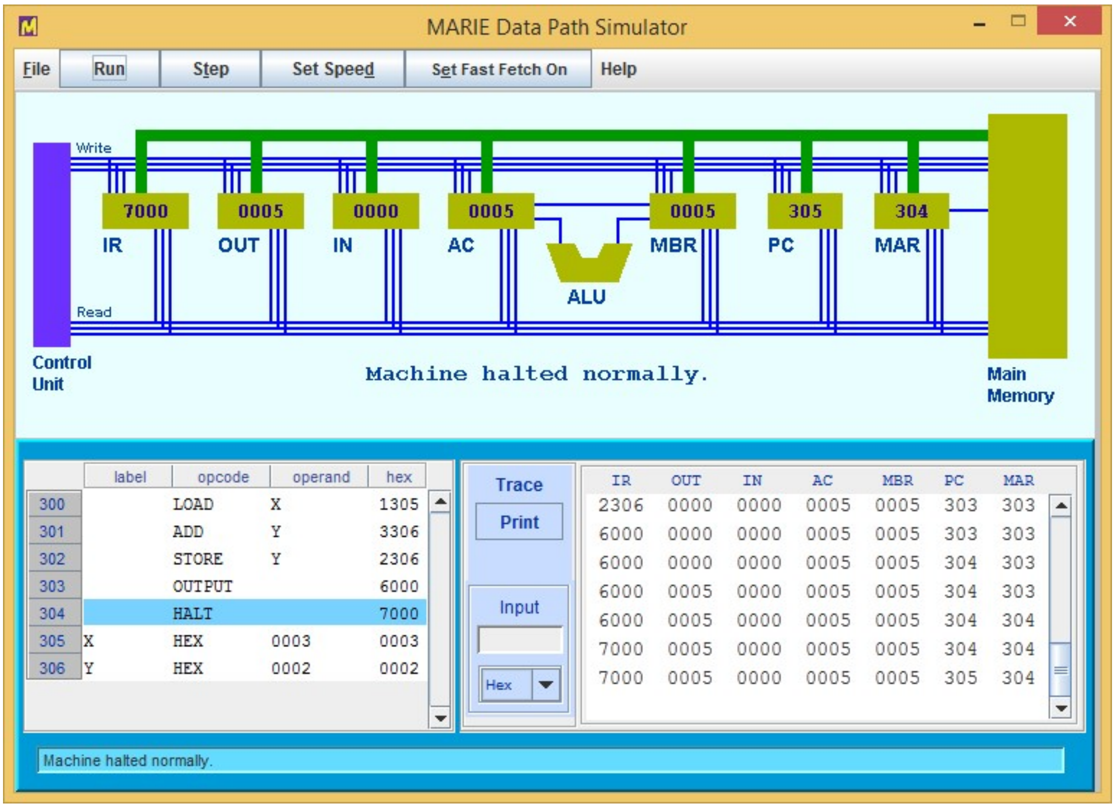

Figure 2: MARIEDataPath environment Source: NULL; LOBUR 2010

Materials and Methods

The methodology used in the survey with the students was based on an exploratory study by accessibility, with quantitative approach regarding the students profile and qualitative regarding the evaluation of their perception of learning with respect to the MARIE CPU Simulator. The sample consisted of thirty one (31) students from Universidade Presbiteriana Mackenzie, in the School of Computing and Information Technology.

The data collection instrument, in relation to the students' perception of their learning experience interrelating the theoretical part with the simulator, was presented to the students at the end of the class, seeking to capture a first impact on the use of the simulator. This instrument consists of a questionnaire with 28 variables (questions).

The variables are divided into four categories (see Table 1), namely: Respondent's profile; 2) Student's perception of overall achievement; 3) Student's perception regarding the ease of understanding of the subject using the simulator; 4) Student's perception regarding the ease of understanding of the internal operation of the processor using MARIE simulator (LABES, 1998 e VIERRA, 2009).

The questionnaire was handled to the students with explanatory instructions, the purpose of the study, the voluntary nature of participation, in addition to ensuring the anonymity of participants. The quantitative and qualitative data present in the questionnaires were processed using IBM SPSS® software. The analysis of information was conducted through descriptive statistics, using measures of central tendency (mean, median) and the corresponding standard measures of dispersion and percentiles, as well as absolute and relative frequency, which are the only ones presented in this study.

We also used the Spearman correlation coefficient, because unlike the Pearson correlation coefficient, it does not require the assumption that the relationship between the variables is linear, nor does it require that the variables are measured in class interval; it can be used for variables measured at the ordinal level. The Spearman ρ coefficient varies between -1 and 1. The closer to these extremes, the greater the association between the variables. The negative sign of the correlation means that the variables vary in the opposite direction, that is, the highest categories of a variable are associated with the lowest categories of the other variable. (LARSON and FARBER, 2009).

Data Analysis

The research variables are ordinal and divided into four groups according to their purposes, as shown in Table 1.

Table 1 Relationship between the variables of the questionnaire and their functions

Variable or statements	**Purpose of evaluation**
V1 to V4 (gender, age, income and semester)	(1)
V5. I have difficulty with the subject.	(2)
V6. I have failed the same subject.	(2)
V7. I find difficulty in other related subjects.	(2)
V8. It is easy to understand the content of the subject.	(2)
V9. I have no difficulty with mathematical logic.	(2)
V10. The use of MARIE simulator is easy.	(3)
V11. Establishing the relationship with the theory has become easier with the use of MARIE simulator.	(3)
V12. I prefer when the teacher uses the MARIE simulator.	(3)
V13. I prefer when I use the MARIE simulator.	(3)
V14. With MARIE simulator I can understand what happens internally to the device.	(4)
V15. I have failed the subject of Computer Organization.	(2)
V16. I have failed the subject of Computer Architecture.	(2)
V17. This is the easiest subject of the semester.	(2)
V18. The use of MARIE simulator increased my interest in the subject.	(3)
V19. With the simulator I can study other subjects without teacher assistance.	(3)
V20. I prefer to study without the use of MARIE simulator.	(3)
V21. The use of MARIE simulator facilitated the understanding of how the registers work.	(4)
V22. The use of MARIE simulator facilitated the understanding of how	(4)

the main memory works.	
V23. The use of MARIE simulator facilitated the understanding of how the processor works.	(4)
V24. The use of MARIE simulator facilitated the understanding of how registers relate to the main memory.	(4)
V25. The use of MARIE simulator facilitated the understanding of how registers relate to the ALU.	(4)
V26. The use of MARIE simulator facilitated the understanding of how registers relate to the operation of the processor.	(4)
V27. The use of MARIE simulator facilitated the understanding of how the main memory relate to the processor.	(4)
V28. The use of MARIE simulator facilitated the understanding of how the main memory relate to the operation of registers.	(4)

Legend of field Purpose of evaluation:

(1) Respondent's profile
(2) Student's perception of overall achievement;
(3) Student's perception of the ease of understanding of the subject using the simulator;
(4) Student's perception regarding the ease of understanding of the internal operation of the processor using MARIE simulator.

The variables were initially addressed by means of absolute frequency (due to the small size of the sample) of each category, the results of which are shown in Table 2, Table 3 and Table 4 below:

Table 2. Student's Profile

Answer	**V1**	**V2**	**V3**	**V4**
1	2	15	6	0
2	29	14	6	0
3	X	X	4	27
4	X	X	0	3
5	X	X	3	1
6	X	X	2	0
7	X	X	4	0
8	X	X	6	0

V1 scale (gender)
(1) male; (2) female

V2 scale (age group)
(1) 15 to 20 incomplete;
(2) 20 to 25 incomplete;
(3) 25 to 30 incomplete;
(4) 30 to 35 incomplete;
(5) 35 to 40 incomplete;
(6) 40 to 45 incomplete;
(7) 45 or above.

V3 scale (income)

(1) I have no income at the moment; (2) R$ 1,000.00 to R$ 2,500.00; (3) R$ 2,501.00 to R$ 4,000.00; (4) R$ 4,001.00 to R$ 5,500.00; (5) R$ 5,501.00 to R$ 7,000.00; (6) R$ 7,001.00 to R$ 8,500.00; (7) R$ 8,501.00 to R$ 10,000.00; (8) Above R$ 10.000,00

V4 scale (academic semester)

(1) First; (2) Second; (3) Third; (4) Fourth; (5) Fifth; (6) Sixth; (7) Seventh; (8) Eighth

Table 3: Student's perception of overall achievement.

Answer	V5	V6	V7	V8	V9	V10	V11	V12
1	4	**23**	5	0	2	5	3	3
2	9	3	10	2	2	7	2	6
3	**14**	1	**12**	**15**	8	**11**	**13**	8
4	0	0	4	14	**16**	3	11	**10**
5	0	4	0	0	3	5	2	4
Total	31	31	31	31	31	31	31	31
Answer	**V13**	**V14**	**V15**	**V16**	**V17**	**V18**	**V19**	**V20**
1	4	3	**27**	**25**	4	3	3	9
2	8	1	0	1	9	7	11	6
3	8	**11**	2	2	**13**	**12**	**13**	9
4	8	10	0	0	4	4	2	4
5	3	6	2	3	1	5	2	3
Total	31	31	31	31	31	31	31	31

V5 to V20 scale

(1) I totally disagree with the statement; (2) I disagree with the statement; (3) I do not disagree nor agree with the statement; (4) I agree with the statement; (5) I completely agree with the statement

Table 4: Student's perception regarding the ease of understanding of the relationship of the structures and operation using MARIE simulator.

Answer	V21	V22	V23	V24	V25	V26	V27	V28
1	2	3	2	1	2	2	1	2
2	2	1	1	2	4	3	5	3
3	**14**	**13**	**14**	**14**	**16**	**14**	**14**	**12**
4	9	10	8	9	5	7	5	7
5	4	4	6	4	4	4	5	6
Total	31	31	31	31	31	31	31	31

V21 to V28 scale

(1) I totally disagree with the statement; (2) I disagree with the statement; (3) I do not disagree nor agree with the statement; (4) I agree with the statement; (5) I completely agree with the statement

Table 5 shows the variables V21 to V28, which are specifically related to the learning involving the MARIE simulator, indicating their cumulative relative frequencies.

Table 5: Cumulative relative frequency of variables V21 to V28

Answer	V21	V22	V23	V24	V25	V26	V27	V28
1	6%	10%	6%	3%	6%	6%	3%	6%
2	13%	13%	10%	10%	19%	16%	19%	16%
3	58%	55%	55%	58%	71%	65%	68%	58%
4	87%	87%	81%	87%	87%	87%	84%	81%
5	100%	100%	100%	100%	100%	100%	100%	100%

For the variables related to learning, that is, V5 to V28, we tabulated the values of higher concentration of answers, for each variable and their apparent meaning, Table 6.

Table 6: Apparent meaning of the predominant answers in each variable

Variable	Highest occurrence	Apparent meaning
V5	3	The student has average difficulty with the subject.
	1	The student never failed the Computer Architecture subject.
	3	The student has average difficulty in other correlated subjects.
	3	The student has average understanding of the content of the subject.
	4	The student has great facility with mathematical logic.
	3	The student finds it moderately easy to use MARIE simulator.
	3	The student is able to establish with average facility the relationship between theory and MARIE simulator.
	4	The student prefers it when the teacher uses the MARIE simulator instead of the student itself using it.
	NO	There was no concentration in the answers to this variable, thus not allowing a conclusion as to its meaning;
	3	The student is able to understand with average facility what happens internally to the device using MARIE simulator.
	1	The student never failed the Computer Organization subject.
	1	The student never failed the Computer Architecture subject (internal consistency with V6).
	3	The student has average difficulty in the Computer Architecture subject compared to other disciplines of the semester.
	3	The student believes that using MARIE simulator moderately increased the interest in the Computer Architecture subject.

	3	The student believes that the MARIE simulator does not exempt the aid of the teacher.
	NO	There was no concentration in the answers to this variable, thus not allowing a conclusion as to its meaning;
	3	The student believes that the use of MARIE simulator moderately facilitated the understanding of how registers work.
	3	The student believes that the use of MARIE simulator moderately facilitated the understanding of the main memory work.
	3	The student believes that the use of MARIE simulator moderately facilitated the understanding of how the processor works.
	3	The student believes that the use of MARIE simulator moderately facilitated the understanding of how registers relate to the main memory.
	3	The student believes that the use of MARIE simulator moderately facilitated the understanding of how registers relate to the ALU.
	3	The student believes that the use of MARIE simulator moderately facilitated the understanding of how registers relate to the processor.
	3	The student believes that the use of MARIE simulator moderately facilitated the understanding of how the main memory relate to the processor operation.
	3	The student believes that the use of MARIE simulator moderately facilitated the understanding of how the main memory relate to the registers.

Legend: NO = there was no tendency of concentration in one single answer.

With respect to the Spearman coefficient, two groups of correlation between variables were built. They are as follows:

> Group 1: correlation of variables V1 to V4, versus variables V5 to V28. The purpose of the correlations of this group is to observe if there is a significant correlation between the social profile of the student and the others relating to learning and the use of the simulator. See Table 7.
>
> Group 2: correlation of variables V5 to V9 (previous student performance), versus variables V10 to V28 (use of simulator). The purpose of the correlations of this group is to observe whether there is a significant correlation between the previous student performance and the others relating to the use of the simulator. See Table 8.

Below we present Tables 7 and 8, with the Spearman coefficient corresponding to each correlation.

Table 7: Spearman coefficient of the correlations of Group 1 variables

Group 1	V1	V2	V3	V4
V5	**0.141**	-0.105	0.053	-0.049
V6	0.096	**0.364**	-0.104	0.045
V7	0.000	-0.129	-0.257	**0.128**
V8	-0.198	0.157	-0.110	**0.218**
V9	-0.240	0.109	**0.127**	0.075
V10	-0.304	0.116	**0.224**	0.110
V11	-0.125	0.061	0.154	**0.216**
V12	-0.045	-0.046	**-0.037**	-0.063
V13	-0.317	-0.010	-0.074	**0.081**
V14	**0.100**	-0.302	0.093	-0.053
V15	-0.101	**0.313**	0.096	0.186
V16	0.149	**0.273**	-0.114	0.061
V17	0.124	**0.165**	-0.034	-0.011
V18	-0.275	0.007	-0.056	**0.293**
V19	-0.328	0.028	**0.033**	-0.037
V20	**0.371**	0.057	-0.256	0.247
V21	0.037	-0.172	**0.172**	-0.079
V22	0.023	-0.147	**0.138**	-0.101
V23	0.000	-0.244	-0.077	**0.191**
V24	-0.031	-0.032	**0.022**	-0.068
V25	-0.078	0.010	**0.167**	-0.229
V26	0.101	0.007	**0.125**	-0.136
V27	0.108	-0.062	**0.205**	-0.321
V28	0.038	-0.014	**0.128**	-0.389

Table 8: Spearman coefficient of the correlations of Group 2 variables

Group 2	V5	V6	V7	V8	V9
V10	-0.533	-0.260	-0.375	**0.376**	0.193
V11	-0.546	-0.361	-0.358	**0.626**	0.427
V12	-0.078	-0.030	-0.069	**0.046**	-0.123
V13	-0.149	-0.329	-0.167	**0.123**	-0.129
V14	-0.171	-0.519	-0.404	**0.183**	-0.131
V15	0.179	**0.403**	0.026	-0.126	-0.128
V16	0.157	**0.885**	0.200	-0.204	-0.149
V17	-0.184	-0. 002	**0.235**	0.177	-0.009
V18	-0.494	-0.428	-0.271	**0.303**	0.237
V19	-0.409	-0.092	-0.150	**0.142**	-0.074
V20	0.294	0.161	**0.322**	-0.031	-0.178
V21	-0.400	-0.141	-0.162	**0.314**	0.230
V22	-0.444	-0.169	-0.188	**0.347**	0.272
V23	-0.353	-0.151	-0.039	**0.511**	0.232
V24	-0.359	-0.078	-0.299	**0.368**	0.347
V25	-0.429	-0.249	-0.343	0.174	**0.320**
V26	-0.244	-0.062	-0.351	0.303	**0.377**
V27	-0.301	-0.144	-0.241	0.241	**0.261**
V28	-0.303	-0.110	-0.291	**0.228**	0.062

Final Considerations

In the course of the class, using the simulator presented, it can be seen that it is possible to provide an appropriate measure of realism to the group of students that would only be possible in an electronics laboratory using mounting boards, integrated circuits and measuring instruments (oscilloscopes, logic analyzers and multimeters).

With these results, it can be inferred, in a qualitative manner yet, that the desired results of teaching and learning have been achieved. Therefore, it is important to allow a continuity of experiments so that quantitative studies can be carried out in order to enable the development of a more in-depth analysis of the impacts that this type of instrument generates in the student learning level.

Thus, for a more objective analysis, it is understood that there should be a statistical follow-up of the classes where the simulation technique is used, compared with others using the conventional method. It would also be important for a quantitative measure of their impact could be obtained.

Regardless of further studies, with the experiments developed it was possible to observe that the techniques applied have caused a significant interest among students, including with regard to the continuity of studies focused on the construction of other circuits in the simulator environment.

It is worth noting also that after the application of the technique, the students have proved to be able to satisfactorily resolve the vast majority of the problems posed in class and on tests.

With the processing of data using descriptive statistics, the following inferences can be made based on Table 5:
The student realizes that the use of Marie simulator facilitated, at least above average, their learning in relation to:

- registers (V21).
- main memory (V22).
- how the processor operates (V23).
- how registers relate to the main memory (V24).
- how registers relate to the ALU (V25).
- how registers relate to the processor (V26).
- how the main memory relates to the operation of the processor (V27)
- how the main memory relates to registers (V28).

With respect to the teacher, it was found that their activity in the classroom changes considerably, in the sense of not requiring the various repetitions of the concepts involved that usually occur, requiring an assistance that seeks to facilitate the use of the simulator, as well as clarify the concepts that eventually are not as clear for some students.

The correlations developed using the Spearman coefficient indicate, in Tables 7 and 8, the following evidence:

a) Group 1 Correlations

- V1 (gender) has no correlation with the other variables from V5 to V28, except V1 in relation to V5; V1 in relation to V14 and V5 in relation to V20 where the highest value for the Spearman coefficient was found for the category.

- In relation to V2 (age group) there is an apparent correlation with V6 and V15, indicating that older students are more prone to failure in the subjects of Computer Architecture and Organization.

- In relation to V3 (income) of failure and other variables from V5 to V28, its influence appears in a number of variables, but without any significant Spearman coefficient except V10 and V27, indicating certain ease of use of Marie simulator as incomes rise.

- In relation to V4 and other variables from V5 to V28, its influence appears in a number of variables, though without any significant Spearman coefficient except for V17 and V20, indicating an improvement in the understanding and interest in the Computer Architecture subject.

a) Group 2 Correlations

- In relation to V5 (difficulty with the subject) and the other variables from V10 to V28, no significant correlations were found, except V20, pointing to a tendency of preference to study without the simulator.

- In relation to V6 (existence of previous failure) and the other variables from V10 to V28, its influence appears in a number of variables, though without any significant Spearman coefficient except for V15 and V16, indicating an improvement in the understanding and interest in the Computer Architecture subject.

- In relation to V7 (difficulty in correlated subjects) and the other variables from V10 to V28, its influence appears in a number of variables, though without any significant Spearman coefficient except for V17 and V20, pointing to the belief that the subject is easy and the students prefer to study without using the Marie simulator.

- In relation to V8 (facility to understand the contents of the subject) and the other variables from V10 to V28, its influence is strong in a number of variables, with the highest concentration in relation to Spearman, in V11 and V23, pointing to the belief that the subject is easy and the students prefer to study without using the Marie simulator.
- In relation to V9 (having no difficulty in mathematical logic) and the other variables V10 to V28, its influence appears in a number of variables, but without any significant Spearman coefficient except V25, V26 and V27, pointing to the belief that the Marie simulator improved learning and understanding, the interoperation of the structures of a virtual processor.

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