The use of MARIE CPU Simulator in Computer Architecture Course: A Case Study of student's perception of learning and performance.

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ABSTRACT

This study aims to show results of employing a case study in the use of Active Learning Practices in the Computer Architecture discipline. The practice in question is the use of Marie® CPU Simulator as a practical tool in the development of the course. The methodology of the study aims to verify whether the use of Marie® CPU Simulator contributes to improving the learning of the Computer Architecture discipline, especially whether it provides a better understanding of the parts that integrate the architecture of a given CPU, with an explanation of the function of the parts, and their interrelationship. This study shows the first results of a more comprehensive study on the use of active learning practices, using software in high-tech disciplines of an information system course. The secondary purpose is to show the application of the case study as a methodology outside the usual areas, such as: medicine, psychology and business administration. This study seeks to show the advantages and limitations found, highlighting its potential in the academic field in relation to the use of active learning practices in lessons of technical subjects, such as Computer Architecture, without losing scientific thoroughness in data processing and in the research methodology.

Keywords: Marie® CPU Simulator, Computer Architecture, Active Learning Practices.

1. CONCEPTUALIZATION OF ACTIVE LEARNING PRACTICES

Computer Simulation as an Active Learning Practice

Abstract concepts are essential to the understanding of Computer Architecture and Organization. They are also a source of difficulties for many students, many of whom struggle even with the basic concepts. An interesting approach to help students understand abstract concepts is the use of computational resources. These resources help students and teachers in computer representation, via simulation, to study abstract concepts.

Simulation is a form of experiential learning. Simulations consist of teaching scenarios, where the student is placed in a world defined by the teacher. They represent 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 and the success of these simulations is determined by the participant's involvement. The goal is to acquire knowledge and understanding.

Among some of the main advantages of simulation are:

- It is a pleasant and motivating activity
- It enhances the understanding of more subtle aspects of a concept / principle
- It promotes critical thinking

The purpose of using computers in education is to integrate them in the learning process of the curricular concepts in all modalities and levels of education, being able to act as facilitator between students and the construction of their knowledge, [1]. This strategy represents an active learning practice, a process by which students engage in activities, such as reading, writing, discussion or problem solving, which promote the analysis, synthesis and evaluation of the contents presented in class.

Teachers cannot distance themselves from the educational content; however, it should be presented through new and attractive teaching dynamics. In this context, it is understood that active learning practices can be used to improve the interest and learning of students, representing valuable tools to teach the content required for their education.

Teaching through active learning practices is essential in computer hardware courses. This view is supported by the literature on education, considering that students are able to better learn the concepts of computer hardware through practical activities that illustrate the theoretical concepts.

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.

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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.

2. 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 [2] 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) [3] 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 MARIE Sim environment is shown below in Figure 1:

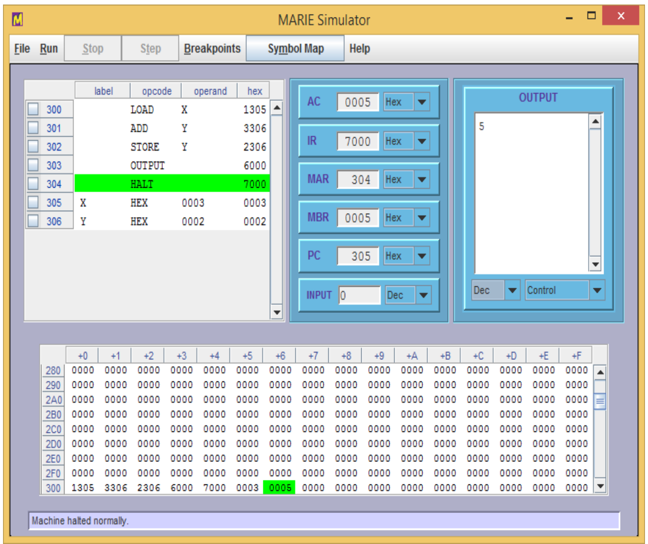

Figure 1 – MARIE® Sim Environment Source: [3]

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, MARIE® DataPath. Figure 2 shows this environment.

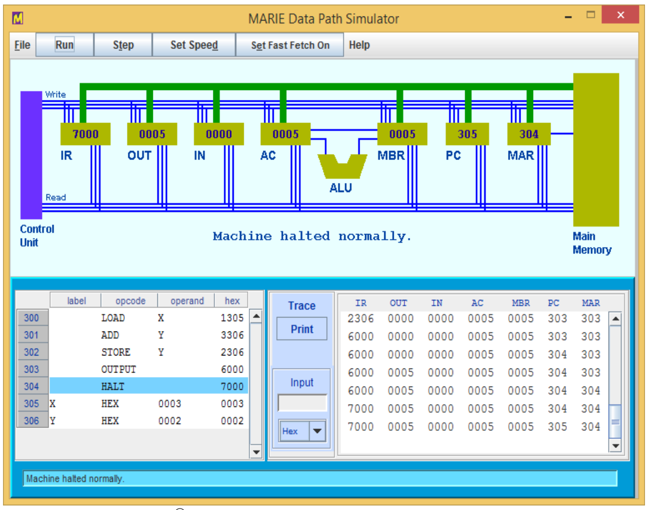

Figure 2: MARIE® DataPath environment Source: [3]

3. CONCEPTUALIZATION OF CASE STUDY

According to [4], the case study is predominant in research studies in the medical and psychology areas (in the survey and structuring of the patient's history), usually as a method of study to determine a diagnosis.

According to [5], the case study method had already been introduced by Christopher C. Laugdell, in 1890, in law education in the United States. Currently, it is used in research studies in areas of knowledge such as education, business administration, business, entrepreneurship, etc.

As for [6] the case study as a research modality dates back to Bronisław Malinowski, considered the founder of anthropology, later in 1930, who uses the case study for research studies on events, processes, organizations, groups, communities in anthropology.

Despite the historical aspects of the methodology, there are several authors who present the method in different ways, including: [7], in addition to: [8], [9] and [10], the last two have used the method in the education field.

According to [10], the case study is a means of organizing data, preserving the unitary nature of the subject studied. He considers the unit as a person, a family, a company, a process within a company, a group of people, etc.

Thus, the object of study becomes a construct, which is related to this object, and therefore, the case study intends to study this unit, which is ultimately the object of study. According to [7], the case study represents the investigative empiricism and its relationship with the logic of planning, collection and analysis of data. It may include single and multiple case studies, as well as quantitative and qualitative research approaches, which is the approach of this study.

According to a few authors, the case study is characterized by the interest in individual cases rather than the research methods it may encompass, but not everything can be considered a case, because a case is a specific unit, a limited system whose parts are integrated.

For [9], the case study as a research strategy is a study that can be simple or complex, but that should always be clearly defined. It may be similar to others, but is also distinct because it has a particular and unique interest. On the other hand, the method has great potential to be used in research studies in the education field.

According to the authors mentioned above, the case study can be understood as a methodology or the choice of an object of study and aims at studying a specific, well-defined and

contextualized case, especially with regard to the collection of information.
The most common case studies are those that focus on an individual or multiple unit, in which various studies are conducted simultaneously: various individuals, various organizations, for example, which is the category of this study. According to [11], [7] and [10], depending on the purpose of the research, the case study can be classified as intrinsic or particular, when it seeks to better understand a particular case, and collective, when it extends the study to other related instrumental cases seeking to broaden the understanding of an even larger set of cases. Based on these categories, researchers should seek what is common in each case and the final result will probably show something original as a result of one or more of the following aspects: context, nature, chronology, and other similar cases and their informants.
[10] states that for the case studies, the priority is given to the qualitative approach of the research, the fundamental characteristics are the interpretation of data in the context; the constant search for new answers and questions; the complete and thorough portrayal of reality; the use of a variety of information sources; the possibility of generalizations and the revelation of the different views on the subject matter.

The case study and its stages

Similar to any research methodology, the case study is usually structured based on a small number of questions and hypotheses. Every case can be decomposed into its constituent parts, for example, in the medical field, the components of a clinical case are: symptoms, evolution, results and consequences. Thus, a case study can be elaborated with the identification of its most relevant components, or assign them relative degrees of importance depending on the case.
There is another misunderstanding with regard to the application of case studies that should be mentioned, it is the understanding that, because it uses one or few units, it a type of research very easy to be conducted. This statement simplifies the level of complexity involved in this research modality and the scientific thoroughness required for its planning, analysis and interpretation.
According to [7] and [5], the study case does not accept a rigid script for its delimitation, but it is possible to note that it is delimited by four phases: a) delimitation of the case-unit; b) data collection; c) data selection, analysis and interpretation; d) preparation of the report.

a) The first phase consists of defining the unit that constitutes the case, which requires that the researcher understands which data are sufficient to reach the understanding of the subject as a whole.
b) The second phase consists of data collection, which is usually conducted through various quantitative and qualitative procedures: observation, document analysis, interview, questionnaire, data survey or content analysis. A great use of case studies is found in exploratory studies.
c) The third phase is represented by data selection, analysis and interpretation. The data selection should consider the objectives of the study, and only the ones selected should be analyzed. The researcher must determine its analysis plan in advance and consider the limitations of the data collected and the quality of the sample, as it is necessary for a rational basis for making generalizations based on the data collected.
d) The fourth phase is represented by the preparation of partial and final reports, which should be preferably concise.

Structure of the Case Study

Similar to all research studies, the original case study of this research contains all the steps required by the Brazilian Association of Technical Standards ABNT [12], that is, cover; cover page; abstract; summary; introduction; methodological procedures; delimitation of the case unit (reality of the case), data analysis; final considerations; references; appendices and annexes. This study will focus on: methodological procedures, data analysis and final considerations.
The methodology used in this case study aims to verify the following hypothesis: 1) whether there is any improvement (from the student's perspective) in the learning of the Computer Architecture discipline, using the Marie® CPU simulator in the practical exercises of the subject, that is, Spearman's coefficient different from zero.
As the methodological procedures, this study includes the following topics:

a) Explanatory classes in the development of the Computer Architecture discipline.
b) Practical classes, approaching the same content, using the Marie® CPU simulator.
c) Questionnaire assessing the students' perception of learning.
d) The questionnaire has three distinct sets of variables: student profile, ease of learning with other Computer Architecture related disciplines, such as Computer Organization and finally, the perception of the ease of learning Computer Architecture using the Marie® CPU simulator.
e) Data processed with the use of SPSS version 25 [13], to establish a correlation between the variables, both qualitative and quantitative. For the correlation, the Spearman's coefficients were used [14].
f) This is the study of a preliminary case (final study estimated to be completed in 2017) that secondarily seeks to validate the questionnaire, scales and interrelationship between the practical and actual aspects of learning and the abstract and theoretical aspects of the Computer Architecture discipline.
g) Exploratory research based on accessibility [11]; [6]; [14], which led to a sample of only 40 students, but suitable for this preliminary phase of the study.
h) The variables from V5 to V29 are qualitative and ordinal, measured using the 5-point Likert scale, as follows: (1) I totally disagree with the statement; (2) I disagree with the statement; (3) I neither agree nor disagree with the statement; (4) I agree with the statement; (5) I completely agree with the statement;
i) The variables included in the questionnaire of the study were distributed as follows:

Table 1: Groups and purpose of the variables in the questionnaire

Purpose	Variable	Content in the questionnaire
Assess the student profile (Group 1)	V1	Gender
	V2	Age
	V3	Income
	V4	Semester
Assess the learning profile (Group 2)	V5	I have difficulty with the subject.
	V6	I have failed the same subject.
	V7	I find difficulty in other related subjects
	V8	It is easy to understand the content of the subject.
	V9	I have no difficulty with mathematical logic.
	V10	The use of MARIE® simulator is easy.
	V11	Establishing the relationship with the theory has become

		easier with the use of MARIE® simulator.
Perception of learning using the Marie® Simulator (Group 3)	V12	I prefer when the teacher uses the MARIE simulator.
	V13	I prefer when I use the MARIE® simulator.
	V14	With MARIE® simulator I can understand what happens internally to the device.
	V15	I have failed the subject of Computer Organization.
	V16	The student had already failed Computer Architecture.
	V17	The use of MARIE® simulator increased my interest in the subject.
	V18	This is the easiest subject of the semester.
	V19	The use of MARIE® simulator increased my interest in others correlated subjects
	V20	With the simulator I can study other subjects without teacher assistance.
	V21	I prefer to study without the use of MARIE simulator.
	V22	The use of MARIE® simulator facilitated the understanding of how the registers work
	V23	The use of MARIE® simulator facilitated the understanding of how the main memory works.
	V24	The use of MARIE® simulator facilitated the understanding of how the processor works.
	V25	The use of MARIE® simulator facilitated the understanding of how registers relate to the main memory
	V26	The use of MARIE® simulator facilitated the understanding of how registers relate to the Arithmetic Logical Unit (ALU).
	V27	The use of MARIE® simulator facilitated the understanding of how registers relate to the operation of the processor.
	V28	The use of MARIE® simulator facilitated the understanding of how the main memory relate to the processor.
	V29	The use of MARIE® simulator facilitated the understanding of how the main memory relate to the operation of registers

j) The variables were crossed to calculate the Spearman's coefficient, as follows: Variables of group 3 (Perception of learning) x Variables of group 1 (Student profile); Variables of group 3 (Perception of learning) x Variables of group 2 (Learning profile);

The issue of delimitation of the case (reality) was addressed within the following context:

a) The most important delimitation of the case is the group of students who make up the sample, based on which we surveyed the perception of learning of the Computer Architecture discipline using the Marie® CPU simulator.
b) A class of 40 students of the second semester of the Information Systems course of UPM.
c) Using of Marie® CPU simulator in alternate classes where the theoretical contents of the classes were reproduced through practical exercises.
d) Period of study: August 2015 to November 2015.

Data analysis was based on the studies of [9], [15], [6], [16] and [17], and was structured as follows:

a) The variables were correlated by using the Spearman's coefficient, seeking to find possible apparent correlations between them.

Table 2: Results of crossing (Spearman's coefficient) the variables of group 1 x group 3

Group (perception of learning)	Group 1 (student profile)			
	V1	V2	V3	V4
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
V29	0,045	0,037	***0,307***	0,102

Table 3: Results of crossing (Spearman's coefficient) the variables of group 2 x group 3

Group 3 (perception of learning)	Group 2 (learning profile)				
	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
V29	-0,207	-0,068	-0,087	***0,395***	0,272

The strongest correlations found in Tables 2 and 3 are shown in Tables 4 and 5, respectively:

Table 4: Strongest correlations found (Spearman's coefficient) between the variables of group 1 x group 3

Group 3 (perception of learning)	Group 1 (student profile)			
	V1	V2	V3	V4
V10	-	-	***0.224***	-
V11	-	-	-	***0.216***
V12	-	-	***-0.037***	-
V13	-	-	-	***0.081***
V14	***0.100***	-	-	-
V15	-	***0.313***	-	-
V16	-	***0.273***	-	-
V17	-	***0.165***	-	-
V18	-	-	-	***0.293***
V19	-	-	***0.033***	-
V20	***0.371***	-	-	-
V21	-	-	***0.172***	-
V22	-	-	***0.138***	-
V23	-	-	-	***0.191***
V24	-	-	***0.022***	-
V25	-	-	***0.167***	-
V26	-	-	***0.125***	-
V27	-	-	***0.205***	-
V28	-	-	***0.128***	-
V29	-	-	***0,307***	-

Table 5: Strongest correlations found (Spearman's coefficient) between the variables of group 2 x group 3

Group 3 (perception of learning)	Group 2 (learning profile)				
	V5	V6	V7	V8	V9
V10	-	-	-	***0.376***	-
V11	-	-	-	***0.626***	-
V12	-	-	-	***0.046***	-
V13	-	-	-	***0.123***	-
V14	-	-	-	***0.183***	-
V15	-	***0.403***	-	-	-
V16	-	***0.885***	-	-	-
V17	-	-	***0.235***	-	-
V18	-	-	-	***0.303***	-
V19	-	-	-	***0.142***	-
V20	-	-	***0.322***	-	-
V21	-	-	-	***0.314***	-
V22	-	-	-	***0.347***	-
V23	-	-	-	***0.511***	-
V24	-	-	-	***0.368***	-
V25	-	-	-	-	***0.320***
V26	-	-	-	-	***0.377***
V27	-	-	-	-	***0.261***
V28	-	-	-	***0,228***	-
V29	-	-	-	***0,395***	-

The positive Spearman's coefficients represent the correlations of same direction, that is, variables that are correlated in the same direction, and those of negative value correspond to the opposite.

4. CONCLUSIONS AND FINAL CONSIDERATIONS

For the conclusions, we extracted the correlations of highest rate from Table 4, which are as follows:

Table 6: Correlations of highest rate between the variables of group 1 x group 3

Group 3 (perception of learning)	Group 1 (student profile)		
	Variable	Spearman	Apparent meaning of the correlation
V10	V3	**0.224**	There is a positive correlation between income and finding the simulator easy to use.
V11	V4	**0.216**	There is a positive correlation between the student attending its regular semester and realizing that it is easy to establish a relationship between theory and practice with the use of the simulator.
V15	V2	**0.313**	There is a positive correlation between the student age and the fact that this same student has already failed in Computer Organization.
V16	V2	**0.273**	There is a positive correlation between the student age and the fact that this same student has already failed in the subject.
V18	V4	**0.293**	There is a positive correlation between the semester in course and the student realizing that this is the easiest subject of the semester.
V20	V1	**0.371**	There is a positive correlation between gender and the student realizing that with the simulator it is possible to study other subjects without the help from the teacher.
V27	V3	**0.205**	There is a positive correlation between income and the simulator facilitating the understanding of registers and the operation of the processor.
V29	V3	**0.307**	There is a correlation between income and the simulator facilitating the understanding of the relationship between the main memory and the operation of registers.

Table 7: Strongest correlations of highest rate between the variables of group 2 x group 3

Group 3 (perception of learning)	Group 2 (learning profile)		
	Variable	Spearman	Apparent meaning of the correlation
V10	V8	0.376	There is a positive correlation between the student finding it easier to understand the content of the subject and finding it easy to use the simulator.
V11	V8	0.626	There is a positive correlation between the student finding it easier to understand the content of the subject and establishing a relationship between theory and practice using the simulator.
V15	V6	0.403	There is a positive correlation between the student having failed the subject and having failed in Computer Organization.
V16	V6	0.885	There is a positive correlation between the student having failed the subject and finding it is the easiest subject of the semester.
V17	V7	0.235	There is a positive correlation between the student finding difficulty in correlated subjects and the increased interest of the student in the subject.
V18	V8	0.303	There is a positive correlation between the student finding it easier to understand the content of the subject and finding it is the easiest subject of the semester in course.
V20	V7	0.322	There is a positive correlation between the student finding difficulty in correlated disciplines and being able to study other subjects without the help from the teacher.
V21	V8	0.314	There is a positive correlation between the student finding it easier to understand the content of the subject and preferring to study with the simulator.
V22	V8	0.347	There is a positive correlation between the student finding it easier to understand the content of the subject and understanding how registers work.
V23	V8	0.511	There is a positive correlation between the student finding it easier to understand the content of the subject and understanding how the main memory works.
V24	V8	0.368	There is a positive correlation between the student finding it easier to understand the content of the subject and understanding how the processor works.
V25	V9	0.320	There is a positive correlation between the student finding no difficulty in mathematical logic and the simulator helping in the understanding of the relationship between registers and main memory.
V26	V9	0.377	There is a positive correlation between the student finding no difficulty in mathematical logic and the simulator helping in the understanding of the relationship between registers and arithmetic logic unit (ALU).
V27	V9	0.261	There is a positive correlation between the student finding no difficulty in mathematical logic and the simulator helping in the understanding of the relationship between registers and the processor operation.
V28	V8	0.228	There is a positive correlation between the student finding it easier to understand the content of the subject and understanding how the main memory relates to the processor operation.
V29	V8	0.395	There is a positive correlation between the student finding it easier to understand the content of the subject and the simulator facilitating the understanding of how the main memory relates to the registers operation.

This first study already indicates some evidence, which should be further analyzed through future studies, seeking to expand the sample and hence achieve more robust evidence.

Among the correlations shown in Tables 6 and 7, below are the ones that already indicate some evidence in this primary study:

1) Income and ease of use of the simulator.
2) Relating theory (abstract world) and practice (real world) in the Computer Architecture discipline.
3) Find the subject easy after using the simulator.
4) Relating the use of the simulator and the understanding of other related disciplines.

5) Using the simulator increased the interest in Computer Architecture.
6) Using the simulator facilitates the understanding of how registers work.
7) Using the simulator facilitates the understanding of how the ALU works.
8) Using the simulator facilitates the understanding of how the main memory works.
9) Using the simulator facilitates the understanding of how the main memory and registers work.
10) Using the simulator facilitates the understanding of how the main memory and ALU work.

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