Evaluation Methods and Techniques for E-Learning Software for School Students in Primary Stages

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Abstract—**This investigation is concerned with the evaluation of an e-learning program developed as an educational tool for the primary grades in real factors in mathematics. The objectives of such a mathematical program designed for school students in primary stages are to encourage them to study mathematics through introducing a lot of examples and exercises that aid them to understand the basic operations on real fraction, as well as to present and explain the subject matter in a clear and user-oriented manner through visual illustrations and alternations. The paper will highlight the advantages of introducing e-learning in schools and describe its later impact on the students' learning process in the Palestinian National Authority schools, through usability tests aimed at investigating the effect of using computerized methods on the achievement of primary grade students in mathematics, in comparison with traditional non-computerized systems of education.**

Index Terms—**Usability Testing, Comparative Evaluation, Human-Computer Interaction, Statistical Methods**

I. INTRODUCTION

MANY students in primary stages face difficulties in understanding school subjects, especially the scientific and mathematical ones. Due to the fact that these students encounter troubles in performing basic mathematical operations such as on real fractions, most of them spend hours in front of computers in order to escape form their home works. Hence, the introduction of e-learning education system might contribute in motivating them to learn more efficiently at home, through making better use of their time in front of computer. In the traditional classroom setting, both students and teachers are often frustrated because students' individual needs are unmet. Students generally have difficulty listening and copying a problem from the board at the same time, so when they begin working assigned problems at their desks they encounter difficulties. Students raise their hands for help, and the teacher moves around the room trying to answer everyone's questions. However, he/she cannot get to every student before time to leave. Students leave the classroom without having all questions answered, and therefore they are unable to complete the assignment. The teacher is exhausted from moving about the room in his/her effort to answer all the questions, and discouraged by the fact that he/she cannot effectively meet the needs of his/her students.

Teachers of mathematics today are eagerly trying alternative methods in an effort to better meet the needs of their students. We want our students to do mathematics assignments themselves, not just listen to and watch mathematics being done by the teacher. We want our students to be motivated to do mathematics. We want them to understand mathematics, pass their classes, and stay in school. We want them to employ new technology –that they are very interested in- in the learning process. We want students to solve problems that they recognize as relevant to their lives. Some effective alternative methods currently in use for teaching mathematics are the following: cooperative learning, problem solving, use of technology, and student projects. In this paper, we are going to discuss the use of technology in teaching. Multimodality is a fundamental feature of the educational tool which allows the student to represent the arithmetical operation on fractions by means of both numbers and pie-charts, so that she gets a coherent view of the different fraction operations. However, it does not only support the students in learning the basic operations related to real fractions, but it also allows them to compare either between two real fractions or real fraction and number. For example, sorting operations in ascending and descending order is possible. There are several factors that influence e-learning such as time to learn, speed of performance, extending global reach, maximizing impact and integration, responding to demand, retention over time, rate of errors, and subjective satisfaction [1]. This study aims at investigating the effect of using computerized method on the achievement of primary grade students in mathematics, in comparison with 'traditional' and non-computerized systems of education. To do so, the paper presents a sample for comparative evaluation that consists of fifteen students, both male and female; all of them learn at schools belonging to the Ramallah district of education. They were divided into two groups of eight and seven students, so that during the comparative evaluation, both groups had to solve mathematical problems based on the

two approaches. The raw data of the experiments were handled statistically by using the Student's test (t-test) [2] and then analyzed by SPSS [3]. Through the usability test, we have found the e-learning education system is superior to the traditional approach. The two approaches were compared with each other by means of an experimental testing, in which some selected usability criteria such as transparency, confidence, effectiveness etc. were used.

The investigation has shown that, on one hand, the use of e-learning has a significant effect on the achievement of students in primary stages; and on the other, there was a positive change in the attitudes of the students towards using the computer in the learning process. As result of the usability testing, it is recommended we carry out more experimental studies on the role of the computers in education for all disciplines of learning. Moreover, the researchers would also like to emphasize the necessity for the development of a computerized syllabus for schools in all the disciplines of education.

II. DESCRIPTION OF THE E-LEARNING EDUCATION SYSTEM AND THE USER-INTERACTION

This section gives an overview about the implemented e-learning education system, which had been evaluated in this investigation. Some implementation aspects, both software-technical and ergonomical will be covered in this part of this contribution. For the people interested in more in-depth know-how about realization of the e-learning, please contact the authors.

To program our e-learning education system for students in primary stages, we have used the JAVA programming language ([4], [5]), where objects consisting of software and graphics had been first built leading to unified exercises appearance. We had designed and implemented several objects such as building blocks of our e-learning system such as a circle class where you can draw a circle with any given number of sectors and that responds to mouse events to color and uncolor these sectors, a rectangle class that can be divided into any number of given rectangles that also respond to mouse events to color and uncolor the internal rectangles, an Arabic numerals text field in which all the typed numbers appear in Indian numerals etc.

The e-learning system allows several kinds of presentations with distinct interaction styles for teaching real fractions using pie-charts, rectangles etc. In the following, we discuss only two styles. Fig. 1 illustrates a snapshot of the e-learning education system during the presentation of user-oriented graphical interface. The multimodal interface, which not only mediates the exercises by graphics, but it also prompts the student to fill-in the corresponding fractions of the visualized pie-chart,
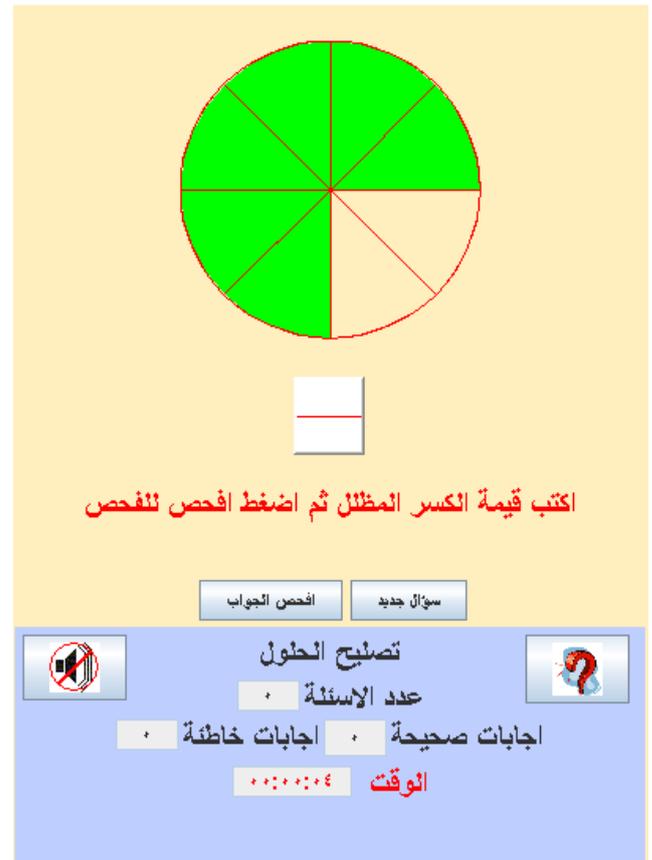

Fig. 1. A snapshot of the e-learning education system while presenting a display, which prompts the student to fill-in the corresponding fractions of the visualized pie-chart

Another kind of exercise offered by the e-learning education system is shown in Fig. 2. With the help of this display, the students have the opportunity to deal with real fraction arithmetic operations. Several human-computer interaction rules for display design were taken into account when having implemented the e-learning system, such as consistency of data display (labeling and graphic conventions), efficient information assimilation by the user, minimal memory load on user, compatibility of data display with data entry, flexibility for user control of data display, presentation of information graphically where appropriate, standardized abbreviations, presentation of digital values only where knowledge of numerical value is necessary and useful etc [1]. After a session of e-learning, the display informs the student about the number of worked-up questions which is refined to correct and incorrect answers. Additionally, the time needed for solving a problem is also displayed.

Fig. 2. A snapshot of the e-learning education system while presenting a display for regular real fraction operations

III. COMPARATIVE EVALUATION OF THE E-LEARNING EDUCATION SYSTEM

A. Introduction

This paper focuses on the statistical evaluation of the e-learning education system for primary grades in real fractions in mathematics compared with the traditional way using textbooks. The evaluation aims at revealing and comparing the characteristics and abilities of the e-learning and traditional approaches. This evaluation was divided into two parts. The first part concerned to find out some usability differences between the four arithmetic operations: addition, subtraction, multiplication and division, provided by the e-learning education system. Results and guidelines achieved through this evaluation help and orient software system developers and user-interface designers in their tasks of both developing of newer e-learning products or optimizing existing ones; whereas, the second part was oriented to compare between the e-learning education system and the traditional learning approach using textbooks. As the traditional learning approach served as a reference, it was possible to compare and analyze the statistical results accomplished using one of the statistical testing techniques available such as ANOVA and t-test. The number of subjects was fifteen, and the t-test technique is suitable for subject numbers less than thirty, thus our choice was for the simple t-test and not for the complicated ANOVA.

As mentioned in former sections, there are several factors that influence e-learning such as time to learn and speed of performance etc. These factors do not only present standards for designing and developing interactive e-learning system, but they also serve as evaluation criteria. While some of these criteria might be subjectively obtained by means of questionnaires, others can be objectively achieved in an automated manner. For instance, objective evaluation measures users' motor-task performance like the time needed or the number of actions necessary to solve an offered scenario. Users' motor-task performance leans on predicting key-stroking or pointing times. In the following, we are going to treat and highlight the major points of the comparative usability testing for evaluating the e-learning education tool and the educational approach.

B. Experimental Environment

The experimental testing and the interviews took place in a primary school located in the Ramallah district of education of the Palestinian Authority. As mentioned, the number of subjects involved in the experiment was fifteen students, both male and female. They were divided into two groups of eight and seven students, where both groups, experimental and controlled, solved mathematical problems using the traditional approach and the contemporary way, the e-learning education system; thus it was possible for us to determine the differences between them according to some usability criteria.

The raw data for this experimental testing had been partly obtained by means of subjective evaluation that was being accomplished by means of interviews and questionnaires. This kind of evaluation is suitable to compare two different conditions, like in our case, the non-computerized approach (the traditional textbook) and the contemporary one (the e-learning education system). During this usability testing, students had to rate questions in seven-point scales. The other part of raw data must have been obtained objectively that was being done by recording the students' interaction with the computer in an experimental session. As the mathematical operations: addition, subtraction, multiplication, and division, of the e-learning education system are executed in computerized form, it is appropriate to compare them objectively according to various usability criteria such as time needed to solve mathematical problems, speed of performance obtained through counting keystrokes and mouse clicks etc.

After finishing the experiments and acquiring the raw data subjectively and objectively, we as usability engineers had organized and evaluated the accomplished data using excel and the statistics package SPSS which allows designers to perform statistical analysis, data manipulation, and generation of tables and graphs. SPSS does not only allow statistical analysis ranging form basic descriptive statistics, such as averages and frequencies, to advanced inferential statistics,

such as regression models, analysis of variance, and factor analysis; but it also contains several tools for manipulating data, including functions for recording data and computing new variables as well.

Finally, the statistical outcome should be analyzed and reviewed by the usability engineers and the system designers, so that the final results helped in revising and optimizing the design of the interactive software system on one hand; and the system designers could have defined new or corrected existing design guidelines for future e-learning tools on the one hand. As a useful means for comparing mean values of two sets of numbers, usability engineers have the opportunity to select between either the Student's test (t-test) [6] or one-way ANOVA, through which a comparison can be carried out, providing us with a statistic for evaluation exposing the statistical significance of the difference between two means. While the t-test is suitable for independent samples, the one-way ANOVA fits for tracing a number of groups on one variable, like finding out the effect of students' learning depending on different studying methods. The t-test is a parametric test assuming a normal distribution and is appropriate when sample sizes are small, i.e. less than thirty [7].

C.   Scenarios

Nowadays, computers do more than just providing information and offering services to people to use [8]. Caroll [9] notes that the design of computing systems is part of an ongoing cycle in which new technologies raise new opportunities for human activity; as people's tasks change in response to these opportunities; new needs for technology arise, like the e-learning technologies. Scenario-based methods both for designing and analyzing are not only beneficial for describing of people using technology in order to reshape their activities; but might be of great significance before a system is built and its impacts felt, [10] and [11].

During a usability testing session, the usability engineer explains to the subject (the student) all operations related to real fraction in very simple and clear way. The education tool represents the arithmetic operations tailored to the students' needs, so that this encourages them for e-learning and studying via the graphical user-display. Several perception-ergonomical aspects were taken into account while developing and designing the e-learning education tool. However, the perception of ergonomics is concerned with designing aspects such as color, shape form, dimension and allocation [12].

Applying perception-ergonomical features in the design of the education tool not only exacerbate the student's intention, but it also feeds him back with the result of his answers. This is achieved by offering audio clues in addition to the visual information for indicating whether his answers were correct or not; the education system informs the student about his success via a message dialog, which appears on the screen. Such dialog message shows a congratulation clapping sound

indicating a correct answer, but if the student has a wrong answer, the education system gives him another chance to answer the question; otherwise the program will give him the correct answer. Providing the education program with this ability makes it distinguishable from other boring traditional applications.

Depending on the operation type, the scenario time varies between 3 minutes and 20 minutes. The e-leaning education system was introduced for the students before having begun with actual experiments consisting of the different scenarios. This introduction included the following activities: entering into the main page, choosing one of the real fraction operations, reading the explanation and examples for a set of offered examples; and solving the given exercises for the selected operation from the easy to the hard. Introducing some examples through the e-learning system might have contributed to skip possible barriers between the students and the computerized education system; as well as reduced students' insecureness regarding contemporary techniques. During a scenario, the students had to solve three different problems for each operation.

D.   Dependent and Independent Variables

In usability testing, a dependent variable is a factor determined by another variable called the independent variable. In other words, the independent variable causes an apparent change in, or simply affects, the dependent variable. In analysis, researchers usually want to explain why the dependent variable has a given value. As mentioned, the values of a dependent variable in different settings are usually compared; whereas, an independent variable is presumed to affect or determine a dependent variable. Usability engineers control/change the independent variable, which causes the dependent variable to change as a result; hence, independent variables act as catalysts for dependent variables. That is, the independent variable is the "presumed cause" while dependent variable is the "presumed effect" of the independent variable [12].

In statistical experiments, dependent variables can be determined subjectively or objectively. Subjective magnitudes are necessary when usability engineers are interested in finding out the personal sensing, feeling or impression of the users while interacting with a software system; Transparency, confidence, fun etc are examples of subjective variables; whereas the objective magnitudes can be obtained through the students' interaction with the system, e.g. the number of keystrokes or scenario time. In our comparative evaluation, the two education approaches: the traditional education way and the e-learning education system, the subjects (students); and the different scenarios represent the independent variables or factors. The name comes from that these terms are independent from each other. The dependent variables are the different criteria such as transparency and efficiency used to compare the factors with each other. They are divided into two parts: objective and subjective. The objective part takes

into account how the subjects interact and deal with the different systems; and will be recorded automatically by the software. The subjective part reflects the user's impression about the interfaces, and it can be acquired by surveys and interviews. During the experiment, subjects have to answer some questions both after every scenario and at the end of a session. For this purpose, they can answer different questions about the various evaluation criteria by choosing on seven-point-scales and percent-scales. Seven-point-scales might look like as shown in Fig. 3.

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		x				

Fig. 3. Seven-point scale

E. *Evaluation Criteria*

This section discusses the evaluation criteria and shows how we can translate these criteria representing the dependent variables into mathematical equations enabling us to involve it in further statistical consideration. As mentioned, the evaluation criteria will be divided into subjective and objective parts. Several usability criteria available as guidelines are defined in international standards such as the ISO 9241-11 [13]. It should be noted that in order to apply these guidelines successfully, designers need to understand the design goals and benefits of each guideline, the conditions under which the guideline should be applied, the precise nature of the proposed solution, and any procedure that must be followed to apply the guideline.

ISO 9241-11 consists of guidelines on usability, providing definitions of usability that is used in subsequent related ergonomic standards. Moreover, ISO 9241-11 explains how to identify the information that is necessary to take into account when specifying or evaluating usability in terms of measures of user performance and satisfaction. Guidance is given on how to describe the context of use of the product and the measures of usability in an explicit way. It does not only include an explanation of how the usability of a product can be specified and evaluated as part of a quality system, for example one that conforms to ISO 9001; but it also explains how measures of user performance and satisfaction can be used to measure how any component of a work system affects the quality of the whole work system in use as well.

In this investigation, various evaluation criteria were used to test the usability of the education system such as effectiveness and efficiency, transparency, navigation, error management, stress, confidence etc. After ending an experiment with a student, the student had to answer the following questions leading to the different subjective criteria: "I like to use computer", "I find the system commands easy to use", "I find learning fraction using computer more interesting for learning", "I am competent with and knowledgeable about

the system", "I feel that speed of performance is reducing the time of performing a specific function", "I find large of information that can be displayed on screen", "When I use the system sequence of screens, I can forward to the next screen or back to previous screen clearly", "When I get an error message, I find that it is helpful in identifying the problem", "The graphical presentation of fractions helps me to understand the real fraction math" etc. It should be noted that the students were asked these questions in Arabic.

The following sections will cover some of these criteria; and we are going to discuss both their definitions and how they can be operationalized into mathematical formulas in order to deal and process them statistically, [14] and [15].

1) *Effectiveness and Efficiency*

Effectiveness and efficiency are very close to each other, and thus they can't be considered separately. In our consideration, effectiveness is related to the interaction between human and the user-interface. The ISO 9241-11 defines effectiveness as the accuracy and the completeness of doing tasks by the human. The tight relation between effectiveness and efficiency confirms the ISO 9241-11 definition, in which efficiency is the effort necessary to achieve effectiveness. In our consideration, we can deal with both values as a result of the effort invested to accomplish a task. The effort is equivalent to the number of the actions of a student, i.e. the number of keystrokes or mouse clicks η_h. The interaction between a student and the e-learning education system is effective if the solving time t_s of a problem is short. Equation (1) reflects the operationalisation of the usability criterion "effectiveness and efficiency" in the form of a mathematical equation.

$$X_{effective} = \frac{1}{2}\left(\frac{1}{\eta_h} + \frac{1}{t_s} \right) \qquad \textbf{(1)}$$

2) *Transparency*

In the human-computer interaction field, there are several meanings available for the term transparency depending on the application filed and its interactive software system. Since we are interested here for definitions concerned with e-learning applications, the definitions of Ulich [16] are suitable for consideration. Ulich designates a system as transparent if the user recognizes whether the dialog system is processing the input command or it is waiting for a new command. Ackermann [17] notes that the transparency is equivalent to the clarity of exposing the system behavior or giving the users the ability to build an internal structure about the interactive software system.

The ascertainment of this value is performed subjectively by means of questionnaires. At the end of an experimental session, the subject answers some questions about her/his impression regarding the transparency of the education system. A seven-point scale is used for this purpose. The usability engineer mediates the questions about the transparency to the students without using complicated expressions. In order to deal with values between zero and one, the acquired data should be normalized for simplifying further operations of the statistical analysis and manipulating data by SPSS. For values acquired by seven-point scales, the formula shown in equation (2) can be used.

$$T_i' = \frac{T_i + 3}{6} \qquad \textbf{(2)}$$

3)   Confidence

In psychology, confidence is well known and is being exclusively used in human-human relationships. Muir [19] transformed the term confidence into human-machine relationships taking into account the importance of confidence as mediator between human and machine. In an investigation of studying confidence in human-machine relationships, Muir [20] stated that usability engineers can obtain significant subjective information about confidence through interviews. Based on this investigation, we also measured the criterion confidence by means of questionnaires. For this purpose, the students had to complete a questionnaire of seven-point scales. Finally, the acquired raw data had to be normalized to values in the interval between zero and one. The normalization can be also obtained as clarified in equation (2).

4)   Statistical Hypothesis

Before discussing the results being accomplished through the usability testing, it will be of great significance if we formalize and define the statistical hypotheses for this evaluation. The dependent and independent variables have been discussed. Other independent variables are the sequences of the scenarios, the arithmetic operations of the e-learning system, and the two educational approaches. In order to compensate for the influence of these variables on the experiment result, we must permutate their sequences. In order to test whether there are significant differences between the mean values, we used the null and alternative hypotheses (H_0 and H_A).

F.   Results and Discussion

We are going to discuss the statistical results achieved by the comparative evaluation after having manipulated the raw data by SPSS, which also allows producing of both tables and graphs. As mentioned, several criteria were measured both subjectively and objectively. In the following discussion, we will highlight some of the criteria discussed, as in this paper we are concerned in presenting the evaluation methods and techniques. Firstly, we will focus on the evaluation, through which we had found the differences between the different mathematical operations itself. This kind of test is important for improving the design of future tools or revising and optimizing the tested ones. Such design is called "iterative design" or continual refinement design process, in which the development procedure is broken into two parts: a preliminary and a refinement [18]. However, it will also be possible to gain knowledge and experience about both information visualization and several psychological education aspects of how students' comprehend maths.

The graph, shown in Fig. 4 represents a comparison between the mean values of the four basic operation, addition, subtraction, multiplication, and division regarding the number of actions in the form of keystrokes and mouse clicks. Every student had to solve three mathematical problems for every operation. As illustrated in Fig. 4, the maximum number of actions equals ca. 50. Moreover, it shows that for most scenarios the division and multiplication operations were the hardest for the students as they require the maximum actions to solve the problems, while the addition and subtraction operations take the minimum number of interaction activities. Such new knowledge and experiences obtained by the evaluation can be utilized in the setting up of novel e-learning tools for scientific topics.
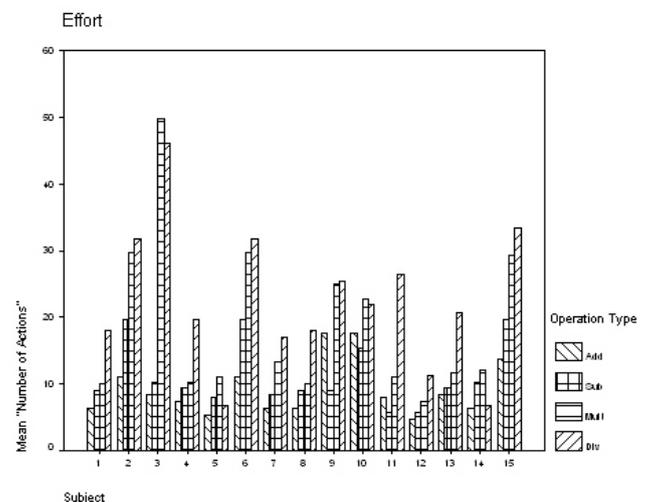

Fig. 4. Comparison between the basic operations according to the number of actions: keystrokes and mouse clicks

Another objective of this usability test was to compare our e-learning education system with the traditional learning approach using a textbook. Since we were considering two styles of learning approaches and intended to find out the differences between them, we might have designed our experiment, so that we could have measured the time needed for solving of mathematical problems. For every operation type, the students had to solve three problems representing the

various scenarios. As previously mentioned, the scenarios were permutated in order to avoid undesirable statistical effects leading to falsification of the experiments results. Afterwards, we will clarify the design of the experiment itself through highlighting the objective criterion "Solving time" for the operation division.

First of all, we had to form a hypothesis as a start point for proving our expectation. However, our hypothesis can be stated as the follows: "When students solve mathematical problems using the e-learning system, they will be faster than using the educational approach based on a math textbook". In this case, the null hypothesis H_0 is that there are no differences between the periods of time necessary for learning. This hypothesis clearly identifies the independent variable for our experiment: the variation of the learning style; hence, the independent variable has two levels: e-learning and traditional. It is obvious that the term "faster" is equivalent to "solving time", "time needed" or "time to learn". In this experiment, we considered the speed, at which a student can accurately solve a problem using one of the two approaches, as an indication of its superiority. Our dependent variable is, therefore, the time needed to solve a mathematical problem. It has been noted that during a session, a student had to solve 3 mathematical problems (scenarios) for every learning style. In order to avoid effects caused by learning, the users were divided into two groups with each group taking a different staring condition.

Despite the fact that the raw data analysis was done for all mathematical operation using SPSS while having compared the two education approaches, we will restrict our discussion only on one operation, namely division. Additionally, we will show in-depth how we can proof whether there are significant differences between the means of two samples belonging to the division operation. This is achieved through the t-test. Table 1 shows a possible set of results for 15 students. The first 8 students solved the mathematical problems using the e-learning system first (experimenting order ET) and then the textbook (order TE).

At the end of Table 1, the mean and standard deviation have been calculated for each condition. We will compare these means using the Student's test (t-test). It is useful to use the Student's test in this statistical evaluation due to the fact that the sample size (student's number) is less than 30. The difference between the mean values of the two approaches is 141.3, but the standard error of difference (s.e.d.) is 94.3. The calculation of s.e.d. is as follows:

$$s.e.d. = \sqrt{\frac{\sigma_E^2}{n_E} + \frac{\sigma_T^2}{n_T}} = \sqrt{\frac{258^2}{15} + \frac{287^2}{15}} = 99.6 \qquad (3)$$

where σ_E and σ_T are the standard deviation of the two approaches: e-learning education system and textbook sequentially, and n_E and n_T the number of data in each condition. Testing the ratio 88/99.6 (mean differences / s.e.d)

against tables of Student's t distribution using 14 degrees of freedom, and is indeed far greater that 5% level (2.1448); this means the chance of getting our results randomly is less that 5 in 100. Thus, we reject the null hypothesis that there are no differences and conclude that the division operation by the e-learning education system is more effectively executed than with textbooks. This result is valid for all the other operations that were experimentally proved similar methods and techniques like the ones shown in this section.

Subject Nr	Exp. Order	E-Learning	Traditional System
1	ET	525	654
2	ET	410	559
3	ET	823	892
4	ET	632	803
5	ET	940	1140
6	ET	1045	192
7	ET	450	605
8	ET	574	704
9	TE	175	351
10	TE	540	661
11	TE	820	991
12	TE	635	805
13	TE	935	1145
14	TE	1042	1192
15	TE	445	615
	maximum	1045	1192
	minimum	175	192
	mean(μ)	666	754
	s.d.(σ)	258	287
	Mean Diff	88	
	s.e.d.	99.6	
	ratio	0.88	

Table 1: Experimental results: solving time for the mathematical operation division

IV. CONCLUSION

In this modest contribution, we have shown how we can evaluate e-learning education systems through comparing it with another reference system, "the traditional" learning approach. Moreover, we have compared the different mathematical operations itself of the e-learning education system, leading us to learn more about cognitive processes of the students in primary stages. It has been shown that, on one hand, the addition is realized as the easiest operation; and the addition/multiplication operation is comprehended more than the subtraction/division on the other hand; thus designers of e-learning education systems for scientific subjects may design mathematical operations and scientific phenomenon composed by the addition operation, as it is already done while having

developed our tool. For instance, we simplified the operation in very clear manner, so that the student can easily understand each operation, such as the division operation, which will be converted to a multiplication for simplification purposes. The results of this stage of the study confirmed and specified the claim of inadequate knowledge and confusion regarding different models of math knowledge representation by the investigated students. For testing the e-learning education system, we took a sample of students from primary grades with different abilities to know the influence of our tool on their cognitive, perceptual and learning abilities. At the end, from our comparative investigation results, it is clear that students having used the e-learning application had better results than students who solved mathematical problems in the traditional way.

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