Detecting errors during the construction of mathematical formulas in a spreadsheet environment: An empirical study involving novice users

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ABSTRACT

In this study we examine the familiarization of students with the basic functions for formula insertion in a general purpose spreadsheet software. Two teaching interventions and two respective follow-up tests were conducted to 124 students of Educational Sciences, with little prior experience in the use of spreadsheets. Through the data collected (test results, registration forms for the students to record any difficulties they had during the tests, video captures of the interactions of the students with the software during the tests) the errors the students made and also any attempts to correct these errors were identified. Our findings indicated that the software error messages and the unexpected results were the main events that prompted the students to recognize their errors.

1.　　Introduction

This study is situated in the field of the use of spreadsheets for supporting teaching and learning, and more generally for supporting the cognitive development of students. More specifically, we examined the support that spreadsheets may offer for the construction of algebraic expressions and therefore the construction of problem-solving models by the students. We focused on the process of the identification and the correction of errors during the algebraic construction of a formula in a spreadsheet environment. The recognition of the students' errors and the process of their correction constitute one of the main topics of research in the field of the Didactics of Science. These errors constitute cognitive obstacles for the students since they do not allow for the construction of new mental models and knowledge. These errors also constitute didactic models for the educators since they do not allow for the implementation of appropriate didactic situations which will support the students' understanding. The study, the recognition of each error the students make, and also the examination of the roots and origins of these errors may allow for the development of appropriate didactic approaches so that these errors will not be repeated. The errors observed during the use of computer-based tools are situated in this framework of research. These are usually errors concerning either the interaction with the user interface of the software, or the problem space itself for which the software is used. Research in this area, and particularly in the use of general-purpose software, such as spreadsheets or databases (Lavidas, Komis, Gialamas, 2011; Fessakis, Dimitracopoulou, Komis, 2005) is still at its early stages. Since, though, such software is often used in the everyday educational practices, it is essential that the students' errors and cognitive difficulties are examined. It is within this framework that this study, on the errors the students make while using a spreadsheet software, is situated.

Spreadsheets constitute some of the most widespread environments that can be used as tools for the quantitative modeling and the solution of a problem (Chorana et al., 2015). They are general purpose pieces of software for calculating and analyzing data, and can be used for organizing, managing, and classifying data, for the graphical and arithmetic representation of the data, and also for drawing conclusions (Karasavvidis, Pieters & Plomp, 2003). The

dynamic of spreadsheets for education and learning has been recognized by a large number of studies (Tort, Blondel & Bruillard, 2008; Lavidas et al., 2007). Spreadsheets constitute cognitive tools that can support the construction of knowledge in an appropriate teaching context (Shim and Li, 2006), they facilitate the mental manipulation of numbers, they support decision-making, and are more efficient for solving verbal mathematical problems (Agyei & Voogt, 2014; Nobre et al, 2012; Lavidas et al., 2011). The multiple representations of a problem and the dynamic linking of the different representations are an important feature of spreadsheets. In a spreadsheet environment, students can easily examine the different representations, such as the algebraic and the arithmetic expressions, the tables of values, and the formulae, and also identify the links among these representations (Schwarz and Dreyfus, 1993; Friedlander & Tabach, 2001; Tort, Blondel and Bruillard, 2008).

Research in the field of education and computer systems indicates that teaching through spreadsheets should be founded mainly on the promotion of their functions through problem-solving processes (Hodnigg, 2005; Jonassen, 2000a). Students using spreadsheets for the solution of problems also learn, during the solution process, some basic functions for inserting formulae in the spreadsheet. These functions are essential for the students to construct models for the solution of the problems they have to solve. The students, nevertheless, during the construction of the models, often confront problems relevant to the incorrect use of the functions for inserting formulae. Considering that the students do not yet have sufficient knowledge on the manipulation of the basic concepts of spreadsheet environments, the implementation of spreadsheets in the problem solving process is, at the least, slowed down. Research on the didactics has to, therefore, focus on the students' errors and the methods with which these errors can be coped with, as well. In this way, new and effective didactic tools can be developed, based on research evidence on the problems, the cognitive difficulties and the errors the students make while working with core concepts of spreadsheet environments.

Errors in the formulae are a quite common phenomenon in the construction of problem-solving models in spreadsheets. There seem to be a number of different types of errors (Aurigemma & Panko, 2014; Panko, 2008). Many of the errors are a result of an incorrect understanding of a situation; there is a distance, that is, between the mental model and the scientific model. In the model of the interaction between the computer system and the user, which Norman (1988) describes as the "cycle of execution and evaluation", many of the errors occurring are attributed to the gulf of execution and the gulf of evaluation. In the case of spreadsheets, the invisibility of the structure of the calculations (Hodnigg, 2005) expands

the gulf of evaluation. After the insertion of a formula in a spreadsheet cell, for instance, the final result is automatically displayed in the same cell. Even though this hidden complexity facilitates engagement and user action, it quite often, nevertheless, confuses the user and hampers the understanding of the mental model of the spreadsheet (Friedlander & Tabach, 2001; Hodnigg, 2005).

Panko and Aurigemma, (2010) identified two categories of errors relevant to the construction of formulae in spreadsheets: qualitative and quantitative errors. Quantitative errors lead to incorrect results and are distinguished into mechanics errors, logic errors, and omission errors. Mechanics errors mainly refer to incorrect typing and mistaken selections of cells, and they constitute errors with a high degree of identification. Logic errors are relevant to an incorrect construction of a formula, they are mainly due to an erroneous reasoning, and they have a low degree of tracking. Errors of omission are the most crucial ones since they are relevant to components important for the construction of a formula and are fairly difficult to identify. Qualitative errors are related to the presentation of the model and they are a result of the design. If maintained, expanded or applied in the spreadsheet, they can later lead to quantitative errors.

In this study we focus on the types of errors made by students concerning the insertion of formulae in the spreadsheet cells, during their attempts to construct algebraic formulae which are essential for the construction of problem-solving models. For recording these errors, we developed a taxonomy of errors which includes three categories. The taxonomy was based on the taxonomies of errors by Panko and Halverson (1997) and by Reinhardt and Pillay (2004). The first category is of a conceptual nature, and includes errors caused by insufficient knowledge of the use of relative and absolute references, the use of the built-in functions, and also the use of copy-paste for inserting content in the cells. The second category is of a logic nature and refers to errors caused by incorrect or insufficient logical-mathematical reasoning, and also cases of incorrect use of algebraic symbols. Finally, the third category refers to mechanics errors, that is errors caused by negligence, such as incorrect or insufficient typing in the cells or selection of an incorrect cell with the computer mouse.

Galletta et al. (1997) describe a number of different factors that can contribute to the identification of formulae' errors in spreadsheets: the experience of the individual on the area the problem is situated in and on the use of spreadsheets, knowledge of the basic functions of spreadsheets (Teo και Lee-Partridge, 2001) and the motivation for engagement in the

problem-solving activity, the time available for the problem-solvers and the social context for the construction of the model (Nardi & Miller, 1990), the appropriate error indication, that is the feedback of the software when an incorrect formula is inserted in a cell -corresponding to a specific type of error (Walkenbach, 2004), which constitutes a prompt for error correction by the users (Yerushalmy, 1991).

In this paper, we examine the familiarity of the students with the basic functions for entering formulae in the spreadsheets. We study, more specifically, the knowledge and skills for entering formulae acquired by the students through the process of a teaching intervention on the use of spreadsheets. We assessed the ability of the students to construct an algebraic expression using relative and absolute references, and also their ability to use the integrated (built–in) functions SUM, AVERAGE, IF, and the automatic completion-copying of cells, in the environment of a spreadsheet. The relative, absolute, and mixed references are symbolic definitions of the positions of the cells and are defined by the headers of the column and the line of each cell (Komis et al., 2005).

The study of the students' skills concerning the basic functions for entering formulae in the spreadsheets and the identification of their mistakes will hopefully shed some light on issues relevant to teaching through a computer environment and also it will clarify certain aspects of the employment of this tool for modeling and solving problems. It will, more specifically, support the definition of a didactic context for teaching the use of general purpose software, such as the spreadsheets, in the subject of Informatics, and also their use for supporting teaching in other subjects such as Mathematics in various levels of education. In this sense, it is studying the methods to support computational thinking (Wing, 2006) which is considered crucial for the enhancement of problem-solving skills in a computer environment. Finally, it will contribute to the dialogue on the ability of the students for algebraic expression, and more specifically the future teachers of preschool education. The latter group is particularly important since, over the past few years, the shortcomings of first year students in the field of mathematics and algebraic reasoning have been recognized (Carlson, 2003).
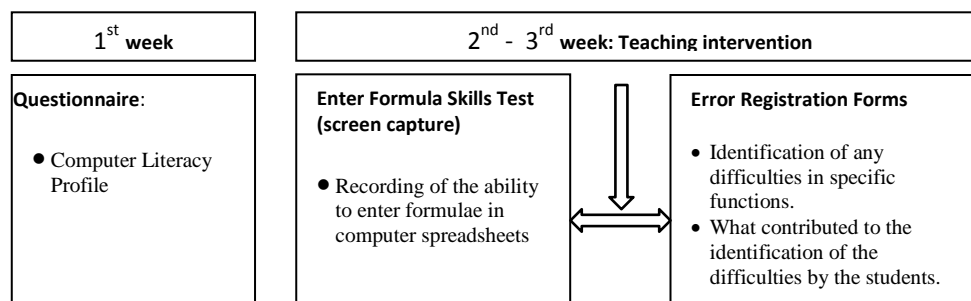
1.1 Research Questions

Our research objectives are: a) the assessment of the students to use some basic functions for entering formulae and b) the definition of the categories of the students' errors on the use of the basic functions of entering formulae, and also whether and which errors the students identify and correct.

2. Research Methodology

For this study we applied two teaching interventions and two respective tests on students of the Department of Educational Sciences and Early Childhood Education at the University of Patras. The interventions took place during the laboratory course on the use of Information and Communication Technologies (ICT) in education and the section concerning the spreadsheets. The data collected and analyzed were relevant to: the assessment of the enter formula functions, the errors of the students, the cases that the students corrected their errors, any other elements indicating what lead the students to identify these errors.

The experimental phase was conducted during the course of three weeks (Fig. 1), in the beginning of the spring semester at the department of Educational Sciences and Early Childhood Education, at the University of Patras. On the first week a questionnaire was given to the students for testing their prior knowledge and experience with computer spreadsheets (Computer Literacy Profile). The questionnaire was based on the Computer Experience Assessment Framework (CEAF) proposed by Palaigeorgiou, Siozos and Konstantakis (2006). Through this questionnaire the knowledge and skills on computer use, acquired through teaching and through practice were assessed.

1st week	2nd - 3rd week: Teaching intervention	
Questionnaire: • Computer Literacy Profile	**Enter Formula Skills Test (screen capture)** • Recording of the ability to enter formulae in computer spreadsheets	**Error Registration Forms** • Identification of any difficulties in specific functions. • What contributed to the identification of the difficulties by the students.

Fig. 1: Research process and relevant data gathered

On the second and the third week, the students had to attend two two-hour sessions (teaching interventions) on the use of spreadsheets, and more specifically MS-Excel. These interventions took place during the formal curriculum of their studies, and the course "Introduction to ICT in Education". They aimed at providing the students with the basic skills for formula entering in the spreadsheet environment, and more specifically the use of relative, absolute and mixed references, use of the fill handle for the data (automatic completion of cells), and use of the built-in functions (e.g. SUM, AVERAGE, IF). In the teaching interventions, the students learned, through solving problems, the functions relevant to the

construction of a problem-solving model. The story of the problem was "realistic" and involved the development of a payroll list of teachers working in a hypothetical school unit.

Upon completion of the teaching intervention, we conducted the student tests for examining whether and at what extent the students learned how to use the basic functions for entering formulae. Two tests were conducted –one for each intervention. Each test took 20-25 minutes and the students had to engage in seven, in total, activities and enter specific formulae in the spreadsheet cells, following the directions. For these tests, one worksheet for each activity and a respective error registration form was distributed to the students. See Fig. 2 for an example of an activity worksheet. The first test consisted of three activities and the second of four activities. In the registration forms the students were asked to describe any difficulties they had encountered in the tests, as well as the indications that helped them realize that they had made a mistake. The interactions of the students with the computer environment were recorded with the use of screen capturing software (Camtasia). Two video captures where, therefore collected for each student: one for each test.

Fig. 2: Example of a task regarding the entering of formulae with the use of relative references

For the analysis of the qualitative data (video captures and open-ended questions in the error registration forms) a coding scheme was developed based on the data and on relevant literature. More specifically, based on the two videos for each student collected during the tests and on the registration forms, the following were identified: a) assessment of the formulae entered by the students, b) the students' errors, and c) the indications that helped the students identify their mistakes. For the assessment of the formulae entered by the students, a three-point scale was used: a) no apparent difficulty in entering the correct formula, b) with some apparent difficulty, the student eventually managed to enter the correct formula, and c) the student did not enter the correct formula. For recording of the errors, a three-point scale was also used, as previously mentioned: a) conceptual errors, b) logic errors, and c) mechanic errors. Finally, for identifying the elements that helped students identify their mistakes, a two-

point scale was used: a) non-acceptance of the function and relevant error indication and b) unexpected result.

In the following section, the analysis of the data, the results obtained and relevant conclusions are presented.

2.1 Participant Characteristics

The student sample participating in the study consisted of 124 students in Social Sciences (Department of Educational Sciences and Early Childhood Education), second and third year of studies (45% and 55% respectively), 19-20 years of age. They had little prior knowledge and experience in spreadsheets. Students with a high level of prior knowledge of spreadsheets, as indicated by the initial questionnaire on the use of computers, were excluded from the study, so as to ensure homogeneity of the sample.

2.2 Presentation and analysis of collected data

In this paper, we focus on the analysis of formula entering into spreadsheet cells during the engagement of the students with the activities included in the tests. In particular, we considered the following formula entering operations: formula entering using relative and absolute references, formula insertion using the built-in functions IF, SUM and AVERAGE, as well as automatic completion – copy of cells and exploitation of neighboring columns in a spreadsheet environment. By the term "automatic completion" we refer to the automatic copy of a formula in neighboring spreadsheet cells. Worksheets were developed using spreadsheets and the students were asked to engage in seven, in total, activities using the relevant functions they had been taught during the teaching interventions.

3.   Results

Based on the proceeding analysis, it seems that the majority of the students are familiar with a subset of the basic spreadsheet operations which involve formula insertion in spreadsheet cells (Fig. 3).
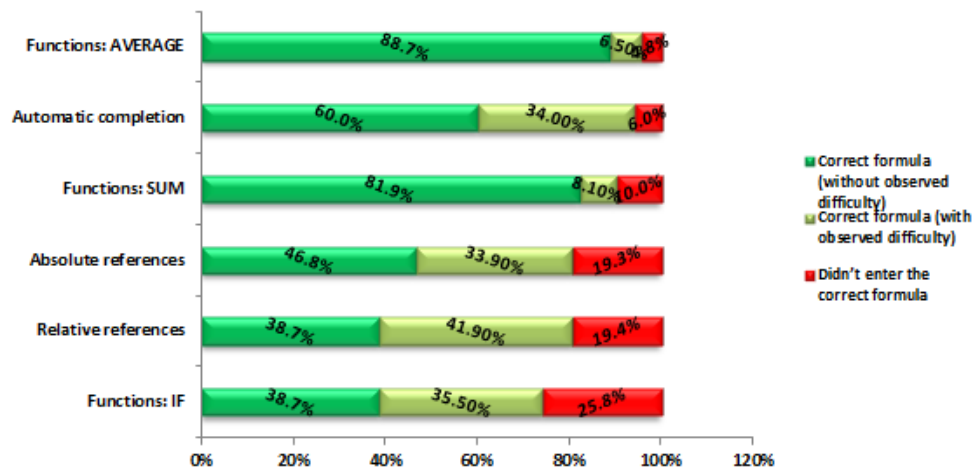
Fig. 3: Familiarity of students with the process of inserting formulae in cells in a spreadsheet environment

In particular, our study indicates that students, in their vast majority (approximately 9 out of 10), were able to insert formulae exploiting the built-in functions SUM and AVERAGE. Most problems were observed in the use of the IF built-in function, since one out of four students did not use this function successfully. Furthermore, students did not seem to have any particular difficulty in entering formulae using relevant or absolute references, since most of them – approximately eight out of ten – succeeded in completing the task or easily recovered from errors. Finally, regarding the ability to copy formulae in spreadsheet cells, i.e. the automatic completion, the vast majority of students (94%) completed the task successfully. Regarding observed error types, our study shows that students tend to correct mechanical errors, while only half of the conceptual errors are finally corrected. In table 1, we summarize our conclusions concerning the correction of errors in formula entering in spreadsheet environments.

As far as the entering of formulae using built-in functions (SUM and AVERAGE) is concerned, very few cases of errors have been observed, while the vast majority of the students managed to correct these errors. However, regarding the IF built-in function, students managed to correct approximately half of relevant logical errors. Also, regarding errors in automatic completion and in the use of relative and absolute references, our study experiment shows that students correct almost all mechanical errors while only approximately half of the conceptual errors.

Table 1: Correction of errors in spreadsheet operations that support formula entering.

	Cases of recovery		
	Mechanical type	**Conceptual type**	**Logical type**
Use of built-in functions: Sum & Average (very few cases of cognitive difficulties)	0%	50%	-------
Automatic completion (very few cases of cognitive difficulties)	--------	81%	-------
Exploitation of relative references (several cases of cognitive difficulties)	100%	53.8%	-------
Exploitation of absolute references (several cases of cognitive difficulties)	60%	64.3%	
Built-in function IF (several cases of cognitive difficulties)	100%	80%	46.2%

As recorded on the error registration form we used, the students' answers to the question regarding what helped them realize that they had made an error show that the automatically generated feedback they received during the insertion of the formula played a very significant and central role. In particular, students mentioned that the following two factors helped them recognize errors: the software generated error messages and the unexpected results (Fig. 3). In the case of automatic completion, the unexpected result of the formula motivated the majority of the students who recognized the error (93.8%) to correct it. Similarly, in the case of the absolute references the unexpected result of the formula motivated the majority of the students (89.3%) to realize the error. On the other hand, regarding the IF built-in function, opinions were almost equally shared: 57.9% of the students who realized their mistake considered that the error message generated by the software was the motivating event, while the rest of the students thought that it was the unexpected result what actually motivated them to realize error. Also, in the case of the relative references, 68% of the students who realized the errors considered that the automatically generated error message motivated them while the rest of the students thought that the unexpected results urged them to identify the errors.

Our study on the type of errors students detected indicated the following: In the case of the automatic completion, only conceptual errors were detected. In the case of the IF built-in function, 10.5% of the errors the students detected were mechanical, 52.6%1 were logical and 36.8% were conceptual. In the case of the use of absolute references, as soon as a software

error message appeared, mainly mechanical errors were detected while in the event of an unexpected result, detected errors were mainly conceptual. In the case of relative references, the error message triggered the detection of errors that were at 58.8% mechanical and 41.2% conceptual, while in the event of an unexpected result detected errors were mainly (87%) conceptual.

At this point, we should highlight the fact that when students make syntactical or logical errors during a formula entering, particular error messages generated by the spreadsheet software inform users about the incorrect action that took place. As soon as such error messages appear, they prompt the students to edit and correct the formulae.
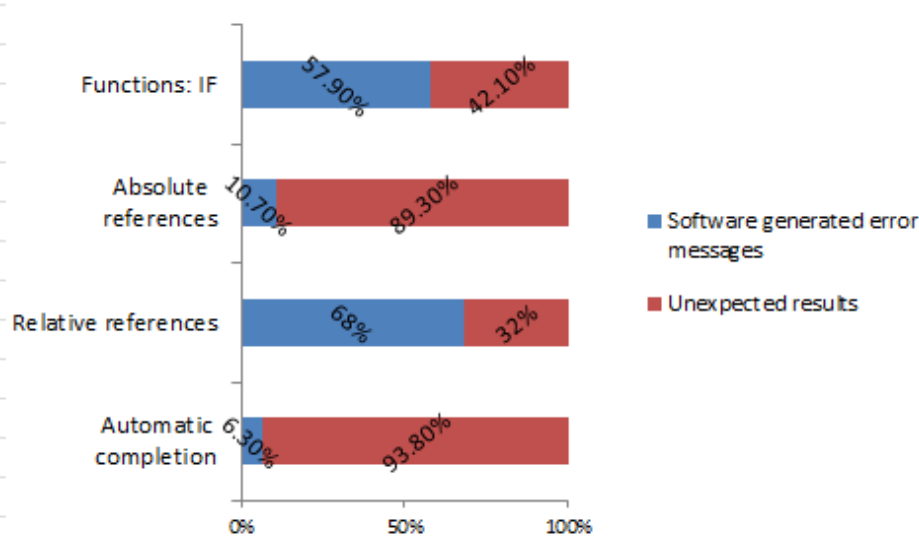
Fig. 3: Factors that urge students to realize the presence of errors.

Our study also indicates that error detection played an important role in the correction of errors and the efficiency of each operation. In operations involving automatic completion, error detection led to its correction in nine out of ten cases. Similar results were observed in the case of the IF built-in function. When students received software feedback, recovery from the error was observed, while in the cases that students reported that they did not see the software feedback, only 15.8% of the erroneous actions were corrected. The qualitative results were similar in the case of formula implementation using relative references: error detection also led to error correction. We reached similar results also for the case of formulae using absolute references, where error detection resulted in error correction at a percentage of 75%. However, in cases where errors were not detected by the students, as recorded in the registration forms, the students did not make similar attempts for error correction. An indicative example involves errors of logical type in the case of the IF function. More

specifically, the vast majority (87.5%) of the students who made logical errors and did not report that they realized their errors, did not make any attempt to correct it.

4.   Discussion-Conclusions

 Our study shows that the vast majority of students were able to enter formulae using the built-in functions SUM and AVERAGE. Most of the problems were observed in the use of the IF built-in function. Furthermore, students did not have any particular difficulties in entering formulae using relevant or absolute references. Finally, regarding their ability to copy formulae in spreadsheet cells, i.e. the automatic completion, the vast majority of students completed the task successfully. These conclusions are in accordance with Lim's findings (2004), in his experimental study with students in Australia in 2004 regarding the use of spreadsheet environments. More specifically, he concluded that students make errors during the implementation of their models and these errors mainly concern the insertion of formulae involving references as well as the use of built-in functions. In this latter case, most of the errors appear when the IF built-in function is used.

Regarding the observed error types, our research shows that students tend to completely correct mechanical errors, while only half of the conceptual errors are finally corrected. These findings are in accordance with those presented by Panko and Halverson (1997) regarding the recovery from errors taking place during the insertion of formulae into cells in spreadsheet environments. As they pointed out, mechanical errors are easily tractable and therefore they present a high recovery rate. The interpretation they provided for this finding focuses mainly on the automatically generated feedback the spreadsheet software returns to users; this type of feedback helps users evaluate immediately the correctness of the inserted formula. Regarding logical errors, Panko and Halverson observed that they present a low recovery rate since—in most such cases—users do not have the necessary scientific background or mathematical skills.

As recorded on the error registration forms we used, students' answers to the question on the indication that prompted them to realize that they had made an error, showed that the automatically generated software feedback they received during the insertion of the formula played a very significant and central role.

As previously mentioned, when students make syntactical or logical errors during formula insertion, particular error messages generated by the spreadsheet software inform users about the incorrect action. As soon as such error messages appear, they seem to immediately motivate the students to edit and correct their formulae. Our findings indicate that these messages play a critical role for the detection and the correction of errors, and the efficiency of each operation. Similar observations were made by Eizenberg and Zaslavsky (2004) since in their research work, reasoning verification was efficient mainly when solvers were informed that their solution was incorrect. To sum up, in most cases, error detection and tracking seem to have a positive effect on the further correction of the error. So, any feedback provided by the spreadsheet software either directly via error messages or indirectly via the unexpected result after formula insertion seems to contribute to error correction (debugging). Epstein et al. (2010) also concluded that immediate feedback promotes acquisition and maintenance of information, affecting the outcome of the users' actions. In a similar vein, Lehman and Herring (2003) pointed out that the benefit gained by immediate feedback is very important since it can potentially reinforce acquisition and maintenance of information throughout the teaching process. Taking into account that a constructive approach to learning should provide not only the necessary environment but also tools for the active construction of knowledge, as well as appropriate feedback during the learning process (Mayes and Fowler, 1999), we believe that direct or indirect feedback provided by spreadsheet environments can certainly contribute to learning since it allows correction of incorrect actions and therefore supports acquisition of knowledge and skills.

Regarding student errors in basic formula insertion operations, our study indicates that errors of mechanical and – in some cases – conceptual type can be immediately identified due to the corresponding feedback generated by the spreadsheet software environment. Furthermore, detection of mechanical and conceptual errors seems to highly contribute to the successful recovery from them; this is not the case for logical errors since the spreadsheet environment does not seem to efficiently support immediate detection.

The findings of our study confirm the dynamic of the computer tools for teaching, specifically in the fields of mathematics and informatics. In this context, educators should teach the use of spreadsheets as tools for modeling and solving problems, by emphasizing the basic functions of formulae insertion, deliberately making errors and therefore creating opportunities for error correction.

Finally, we must note that our student sample was non-random and therefore certain constraints are posed to the generalisation of our findings to the population of the future teachers of preschool education.

Acknowledgements

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