

This is an accepted manuscript of an article published by Taylor & Francis Group in International Journal of Mathematical Education in Science and Technology, vol. 4(6), 893-904 (2013), available online:
<http://www.tandfonline.com/10.1080/0020739X.2013.813979>

Title: A study of the mathematical literacy in a Plant Physiology course and results of interventions aimed at improving undergraduate student's performance.

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Title: Mathematical literacy in Plant Physiology undergraduates. Results of interventions aimed at improving students' performance.

Running head: Mathematical literacy in Plant Physiology students.

ABSTRACT

The importance of mathematical literacy in any scientific career is widely recognized. However, various studies report lack of numeracy and mathematical literacy in students from various countries. In the present work we present a detailed study of the mathematical literacy of Spanish undergraduate students of Biology enrolled in a Plant Physiology course. We have performed individual analyses of results obtained during the period 2000-2011, for questions in the examinations requiring and not requiring mathematical skills. Additionally, we present the outcome of two interventions introduced with the aim of helping students improve their prospects for success in the course. Our results confirm previous research showing students' deficiencies in mathematical skills. However, the scores obtained for mathematical questions in the examinations are good predictors of the final grades attained in Plant Physiology, as there are strong correlations at the individual level between results for questions requiring and not requiring mathematical skills. The introduction of a laboratory session devoted to strengthening the application of students' previously acquired mathematical knowledge did not change significantly the results obtained for mathematical questions. Since mathematical abilities of students entering university have declined in recent years, this intervention may have helped to maintain students' performance to a level comparable to that of previous years. The outcome of self-assessment online tests indicates that though Mathematics anxiety is lower than during examinations, the poor results obtained for questions requiring mathematical skills are, at least in part, due to a lack of self-efficacy.

Keywords: mathematical literacy, online self-assessment tests, Plant Physiology, self-efficacy, undergraduate students.

1. INTRODUCTION

The importance of mathematical literacy in any scientific career is widely recognized. In fact, the direct relationship between years of mathematical courses taken in high school and later results in scientific disciplines at the tertiary level has been demonstrated [1]. Various studies also have reported lack of numeracy and mathematical literacy in students from different countries. Thus, Gross [2] indicated that many teachers from many countries complain about students poor comprehension of basic quantitative concepts. More recently, Koenig [3], also referred the existence of a consensus among teachers about the difficulties of students with basic Mathematics, and Tariq [4] provided evidence of a decline in numeracy skills among Bioscience undergraduates. In a seven year study it was shown that Pharmacy students were not retaining fundamental numeracy concepts and that the level of ability was significantly decreased over the period studied [5]. LeBard et al. [6] indicated that students experience difficulties in transforming their mathematical training into a form that allows them to use it effectively. Low scores for questions that require the application of mathematical skills in undergraduate students of Plant Physiology have also been reported [7] and, additionally despite the number of mathematical questions in the examinations being low, the students' performance in such questions was a good predictor of the final grade, as also shown by Mulhern et al. [8] for Psychology undergraduates.

Part of the students' failure might be attributed to the students' lack of ability to apply their mathematical knowledge in a practical way in the appropriate context (mathematical literacy), and to lack of self-efficacy (i.e. belief in their own ability to successfully overcome these issues). The positive impact of high self-efficacy on students' performance has also been noted by different authors. Thus, Zarch et al. [9] pointed that although mathematical ability has a direct effect on Mathematics achievement, it also has an indirect effect through self-efficacy. Further, Stevens et al. [10] indicated that self-efficacy is a better predictor of achievement in Mathematics than the overall mental ability. The analysis of Kiamanesh et al. [11] on the role of different variables in students' mathematical achievement also showed that self-efficacy is a strong predictor of final results. Additionally, these authors indicated that there is a high correlation between Mathematics self-concept and Mathematics anxiety and that the

latter mediates the effect of self-efficacy on Mathematics performance. Enabling students to engage in their own skills development has been used as a strategy to increase students' performance [12].

In a previous survey, we detected deficiencies in mathematical skills in Biology undergraduates and showed that the average scores obtained for the mathematical questions in the examinations of Plant Physiology varied in parallel with the percentage of successful students [7]. Since the previous study considered the average scores for all students of the same academic year, we have performed a more detailed study through analyses at the individual level of results obtained in the examinations for questions requiring and not requiring mathematical skills, and extended the study to include results obtained over eleven years (2000/01 to 2010/11). Additionally, we present the outcome of two interventions introduced with the aim of helping students improve their prospects for success in the course. The first one was initiated in the academic year 2003/04 and was designed to reinforce their mathematical skills. The second started in the academic year 2009/10, and consisted of the introduction of online tests for self-assessment which also included questions that required the application of mathematical skills for their resolution.

Thus, in this work we tested the hypothesis that the direct relationship previously found between the average scores obtained for the mathematical questions and the final grades held at the individual level. We also evaluated the results of two different interventions related to mathematical literacy, implemented at different moments along the period studied to see whether they could help improve students' performance.

2. METHODOLOGY

The survey consists of results obtained from multiple choice tests used for evaluation in student groups of a Plant Physiology course during the academic years 2000/01 to 2010/11, with an average of 109 students per year (ranging from 58 to 131). The number of tests per course varied from 3 (period 2000-2004) to 4 (2004-2011), as in 2004/05 we added another preliminary examination. Each test consisted of 20 to 45 items, depending on whether it was a preliminary or a final examination, therefore including only part or the whole subject content. This number is lower than usual in multiple-choice tests, despite tests with higher number of items being generally more reliable [13]. However, since our tests were composed of questions that can be

answered quickly, together with others requiring some time for resolving, including some numerical calculations, we decreased the number of items in order to reduce the time which would otherwise be necessary to complete the test and which might have affected students' performance [14]. The exams were not time limited and 80 % of the students finished within 2 h. The adequacy of the tests to the objectives of the course was assessed by calculating the usual parameters in tests based on multiple choice questions (MCQ). The Kuder-Richardson coefficient (KR_{20}) is a measure of the internal consistency and therefore reliability of the tests and can range from 0 to 1. Values higher than 0.5 are considered sufficient for drawing meaningful conclusions [15]. Therefore, tests showing a reliability coefficient lower than 0.5 were not included in the study. The mean reliability of the tests used was $KR_{20} = 0.7 \pm 0.1$. Difficulty indices represent the proportion of correct responses to each of the test items, with a value range from 0 (most difficult items) to 1 (easiest items). Desirable difficulty indices can be estimated as halfway between 100% and the percentage of success expected by guessing and in our tests showed a mean value of 0.5 ± 0.2 . Discrimination coefficients show to what extent a particular item distinguishes between upper and lower scoring students and should range from 0 to 1, as negative values correspond to flawed items that should be discarded. The mean discrimination coefficient of our tests was 0.3 ± 0.2 , a value that can be considered reasonably adequate. The items included in each test were agreed among three faculty members, all of them experienced teachers of the Plant Physiology course. Each item was selected when the three teachers considered that it matched at least one of the objectives of the course. Validity of the tests, therefore, fulfilled the usual standards [15,16].

In the University of Valencia (Spain), until the academic year 2010/2011, Plant Physiology was a compulsory subject taught in the third year of the five-year degree in Biology. This subject had 9 credits (equivalent to 90 hours tuition), 6 of which corresponded to theory classes and 3 to laboratory sessions. Each of the laboratory sessions included a series of exercises and problems that required mathematical skills for their resolution. In 2003-2004 the first intervention was initiated. It consisted of dedicating one of the laboratory sessions to perform such exercises, with additional problems to those already proposed in the rest of the laboratory sessions. The objective of this session was to strengthen the practical use of some chemical, physical and

mathematical aspects required for daily laboratory work, primarily those required to perform the laboratory sessions of the course (Table 1).

From 2009/10, in the context of an inter-facultative project aimed at introducing new technologies in teaching/learning, online self-assessing tests were introduced [17]. The structure of the online tests was similar to that of the examinations, but the results obtained were not taken into account for the students' final grades. The tests were made available to the students prior to their examinations in order to measure the progress of self-learning and to enable the students to reinforce the necessary aspects before the examinations took place, including mathematical skills. The completion of these tests, four per academic year, was voluntary, though participation was strongly recommended, since students could use them to assess their degree of preparation. Further, these tests may highlight the weakest aspects of the students understanding before the examinations so that they could improve individually or through tutorials. The tests could be completed from any computer, including the students' home computer and the only time constrain obeyed a technical reason, as lack of any input during half an hour disconnected the computer from the university network. The KR_{20} corresponding to online tests was 0.85 ± 0.06 .

All statistical analyses were performed using the SPSS Program (v 19.0). Correlation coefficients and significance (bilateral P values) were obtained by regression analysis. The relative influence of factors shown in Table 2 on the slopes obtained was determined by a two-way ANOVA. Significant differences between means were established ($P < 0.05$) through t -tests for paired samples or Tukey's HSD test after one-way ANOVA. Two-tailed z -tests were used for the analysis of proportions ($P < 0.05$).

3. RESULTS

Table 2 shows the results of correlation analysis of the individual scores obtained by Biology students over 11 academic years (2000-2011) on the subject Plant Physiology for questions that require mathematical skills compared to questions that do not require them. As can be seen, t -Student values are significant in all academic years of the period studied. The lowest values were obtained in years with fewer students (2000/01 and 2003/04) or lower proportion of mathematical questions on the tests

(<10%, 2000/01, 2002/03 and 2004/05). Although all correlations were statistically significant, we were interested in knowing the relative influence of these two variables on the slopes obtained. The analysis performed showed that the number of students per year explained only 17% of the variance, while the percentage of examination questions requiring mathematical skills explained 56% of the variance. There was a significant correlation between the percentage of such questions and the slopes obtained in the correlations calculated for each of the academic years between scores for mathematical and non-mathematical questions (Figure 1). In contrast, there was no significant correlation with the number of students (slope = 0.003, $r = 0.42$, $t = 1.38$, $n = 11$, $P < 0.2$).

3.1. Results of intervention 1 (laboratory session dedicated to the resolution of Plant Physiology problems requiring mathematical skills)

The result obtained after dedicating a laboratory session to strengthening the application of the students' mathematical skills was analysed by comparing the average scores of the different courses before (2000-2003) and after (2004-2011) the intervention. We compared the scores obtained for both, questions requiring and not requiring mathematical skills, in order to see whether after the intervention there was any variation in student performance specifically on such questions.

The data obtained (Figure 2A) show that in both periods the average scores are significantly higher for questions that do not require mathematical skills. After the intervention, the average score did not improve significantly for either of the two types of questions. A further analysis was performed to test whether putative differences in the degree of difficulty of the mathematical questions included in the examinations might affect the results. With this purpose, we selected all the identical mathematical questions which were included before and after the intervention. Sixteen different questions were recorded (receiving a total of 987 and 1288 responses before and after the intervention, respectively). Two of the questions resulted in a significantly different percentage of correct answers after the intervention (Figure 2B, inset) but in both cases it was lower than before and, as shown in Figure 2B, dependent t -tests for paired samples did not detect significant differences ($P < 0.05$) between mean results obtained for these sixteen questions (52 % correct answers before, and 46% after, the intervention).

3.2. Results of intervention 2 (completing online self-assessed tests)

Participation in this voluntary activity represented 46% of the students enrolled in the 2009/10 academic course and 41% in 2010/11 (65% and 66% of the students taking the final examinations, respectively). Overall, out of the 113 students taking the final examinations in these two courses, 51 took at least one of the tests available and a quarter of them completed all the online tests. It is interesting that the percentage of students with a final passing grade increased with the number of online tests completed. Thus, only around 10% of students who did not complete any of the tests available got a pass degree, whilst 30%, 40% and more than 80% of students completing, respectively, one, two or three or all the tests proposed passed the subject. These tests included questions requiring mathematical skills in a similar percentage as in the examinations (Table 3). As for the examinations (Table 2), there was a significant positive correlation between the marks obtained at the individual level in both types of questions (slope = 0.48, $r = 0.557$, $t = 6.67$, $n = 101$, $P < 0.0001$).

Figure 3 presents the comparative percentages of correct, incorrect and blank answers obtained by the same students in examinations and in online tests for the two types of questions. There were significant differences for all types of responses between questions requiring and not requiring mathematical skills. The pattern of correct responses was similar for the online tests and the examinations, with greater percentages for non-mathematical questions (12% higher in examinations and 14% in the tests). Interestingly, percentages of incorrect answers for questions not requiring mathematical skills were lower in the examinations and higher in the online tests (5% in both cases, from a total of 1205 and 1514 incorrect answers in the examinations and the online tests, respectively). To be noted is the high proportion of blank answers to mathematical questions, significantly higher than for non-mathematical ones and particularly in the online tests. Since the results of the tests are not taken into account in the course grade, students tend to take more risk when answering (46% of blank answers in the examinations, versus 34% in tests). Despite this, there were around 26% of blank responses for mathematical questions in both types of tests. Since the blank response rate is lower in the tests for non-mathematical issues, the rate of blanks in tests is proportionally greater. Thus, while the percentage of blank answers for mathematical questions in the examinations is only 1.3-times that of the non-mathematical ones, in online tests it is 3.3-times (Table 3).

4. DISCUSSION

The importance of mathematical literacy has been noted by several authors, and it has been suggested that it may significantly affect the employability of graduates [18-20]. At the academic level, we found in a previous study that the average score in the subject Plant Physiology for questions that require mathematical skills for resolution are a good predictor of the students' final grades, though such issues only represent less than 15% of the questions in the examinations [7]. A more extended and detailed study of these results are presented in this paper, showing that there is a highly significant correlation between the scores obtained by the students individually for both types of questions, in all and each of the 11 academic years analysed (Table 2). Since the correlations were made between the scores for mathematical and non-mathematical questions and not between mathematical questions and the global score of both types of questions, the predictive value of results obtained in mathematical questions on the final result in the course is further confirmed by these results. Moreover, its validity as a predictor increases with the percentage of such issues included in the examinations, at least in the range between 10 and 20 %, used in the period studied (Figure 1). Level of qualification in Mathematics was also found to predict overall performance of Psychology undergraduate students [8].

The inclusion of a laboratory session designed specifically to reinforce basic mathematical skills that students need for experimental work in this subject does not seem to have yielded positive results, as the average score on the tests before and after the intervention did not change significantly (Figure 2). This contrasts with results reported by other authors [5,21] who showed that after working quantitative concepts along the course, the students' graphical-mathematical performance improved. In our case, however, interpretation of the results is complex because additional factors should be considered due to the lengthy time span of the study. Thus, there is a potential effect of the change in the structure of secondary education which became widespread in 1996/97. Students from the new educational system reached the third year of Biology, in which Plant Physiology is taught, in 2004/05, i.e. the academic year following the onset of the intervention. This change in the secondary education had the advantage of matching the end of compulsory education to the minimum legal working age, but in the academic sense, it represented a reduction in the number of years, from four to two, of non-compulsory education before university entry. This may be a crucial factor, as it

has been demonstrated that the mathematical background acquired in high school is a determinant of the results obtained in tertiary education by science students [1]. The fact that the results obtained for Mathematics by secondary students at the end of compulsory education have been shown to have worsened after the implementation of the new educational system [22,23] supports this hypothesis. Thus, the intervention might have helped to maintain students' performance to a level comparable to that of students from the prior educational system. Additionally, the decrease of mathematical skills in our students in the last years could also be part of a more global effect, also observed in other countries. Thus, Tariq [4] gave evidence of a decline in numeracy skills in Bioscience students in Northern Ireland during the period 1995-2000 and a seven-year study performed with Pharmacy undergraduates by Malcolm and McCoy [5] also showed a significant decrease over the years 1999-2005.

On the other hand, after recognizing the problem and initiating the intervention, mathematical skills worked in the laboratory session were specifically evaluated and, as a consequence, the requirements regarding the use of Mathematics augmented. This also led to an increase in the percentage of such questions in the examinations, from an average of 9.9% before the intervention to 15.5% in the later period. However, the degree of difficulty does not seem to be a determinant factor, as the mean percentages of correct answers for identical mathematical questions included in examinations before and after intervention 1 did not show significant differences (52 % versus 46 %, $P < 0.05$).

It is a tacitly established consensus among teachers that the teaching effort should not depend on the average results of the whole class but on the presence of any student in the class who improves as a result of that effort. Although our results cannot demonstrate that there has been an improvement in mathematical skills of the students after the intervention, their own perception of the usefulness of this laboratory session is positive and every year they express their interest in maintaining this laboratory session in the Plant Physiology programme.

With respect to the results obtained in intervention 2, the most remarkable observation is the high percentage of such questions left unanswered also in the tests (Figure 3). It has been suggested that an increase in the percentage of mathematical questions left unanswered in examinations may be due to low self-efficacy of the students [7]. The results obtained for the online tests in the present work confirm this

suggestion. Since the purpose of the scores obtained in these self-assessed tests is only that students can measure the progress made, they are not taken into account for the final grades. For this reason, one would expect a very low percentage of blank responses, as there is no risk in decreasing the score if answered incorrectly. This certainly applies to items that do not require mathematical skills and thus, whilst 20% of them are left unanswered in examinations, in online tests they amount to only 7.7%. This small percentage should be representing parts of the subject that students must strengthen to face the real exam. However, the online tests, though being a simulation of the real exam, do not seem to encourage students to answer items that require mathematical skills. The percentage of blank responses to this type of question is similar in both the examinations and the online tests (26%). Since mathematical numeracy required for solving these questions is not subject specific and only needs basic mathematical skills that students have already acquired (see examples in [7]), this data indicates that students do not make the effort to complete the task. Due to the conditions under which the online tests were conducted, Mathematics anxiety should not be a factor significantly influencing the results. Thus, according to Durrani and Tariq [15,24], Mathematics anxiety emerges especially in time-limited situations, which was not applicable to our case. Also, resource limitations have been pointed out as an additional element giving rise to anxiety [25] and since students could complete the tests from home, they were able to use class notes, books and other resources they may have needed. Another important aspect to be considered is the level of perceived threat, that is, the worry about the consequences of failure [26,27] and, as indicated, the online tests were not taken into account for the students' final grade. Thus, our results point to a lack of self-efficacy. As indicated by Siegle and McCoach [28] students with high self-efficacy are able to address new challenges and work more than those with lower self-efficacy. On the other hand, the students' lack of awareness that trying to solve such issues is an exercise that can help them to improve their subsequent performance, may be a contributing factor that hinders their capacity to provide the additional necessary effort to solve these questions.

In summary, the present study, analysing individual-level correlations on data obtained along 11 years, confirms a deficient mathematical literacy in Spanish undergraduate students of Biology enrolled in a Plant Physiology course. However, the data indicate that scores obtained in mathematical questions are, to some extent, good

predictors of the final results in this subject. An intervention conducted to improve the application of prior acquired mathematical knowledge did not modify significantly students' results on mathematical questions. However, since according to published data mathematical skills seem to have declined over the years in students entering university, the intervention may at least have helped to maintain the level of previous years. Analysis of a second intervention conducted through self-assessment online tests completed under lower anxiety conditions than during examinations, shows that students' deficiency in mathematical skills seems primarily due to students' low self-efficacy.

Acknowledgments. We thank Mrs Eunice Martin for correcting the English.

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Table 1. Quantitative aspects worked in intervention 1, starting in the academic year 2003/04, and types of exercises proposed during the lab session introduced in the Plant Physiology programme.

| Aspects worked | Exercises |
|----------------------------|---|
| International system units | Conversion between different units. Use of multiples and submultiples |
| Concentration units | Preparation of solutions, calculation of dilutions, etc |
| Geometry | Calculation of areas and volumes of different plant organs |
| Graphical representation | Plotting of different types of data obtained in the experimental work |
| Spectrophotometry | Application of the Lambert-Beer law, use of extinction coefficients |
| Centrifugation | Conversion between angular velocity and centrifugal force. Selective precipitation. |
| Manometry | Use of the ideal gas law equation. Conversions volume/weight |
| Statistics | Calculation of means, standard deviations, ANOVA analysis, regression and correlation, etc. Use of spreadsheets and statistical packages. |

Table 2. Correlation data obtained for each academic year between individual scores obtained for question requiring and not requiring mathematical skills. The number of students (n) and the percentage of questions in the exams requiring mathematical skills (% MQ) are also shown.

| Academic year | Slope | Correl. coef. | <i>t</i> -Student | <i>P</i> value (bilateral) | n | % MQ |
|---------------|-------|---------------|-------------------|----------------------------|-----|------|
| 2000 / 01 | 0.198 | 0.357 | 2.62 | < 0.02 | 49 | 6.6 |
| 2001 / 02 | 0.405 | 0.602 | 7.23 | < 0.0001 | 94 | 13.3 |
| 2002 / 03 | 0.219 | 0.351 | 3.31 | < 0.002 | 80 | 9.9 |
| 2003 / 04 | 0.208 | 0.319 | 2.10 | < 0.05 | 41 | 16.0 |
| 2004 / 05 | 0.213 | 0.275 | 2.86 | < 0.01 | 102 | 9.8 |
| 2005 / 06 | 0.455 | 0.615 | 7.48 | < 0.0001 | 94 | 17.7 |
| 2006 / 07 | 0.453 | 0.601 | 7.81 | < 0.0001 | 110 | 12.0 |
| 2007 / 08 | 0.518 | 0.644 | 8.91 | < 0.0001 | 114 | 15.6 |
| 2008 / 09 | 0.597 | 0.677 | 7.64 | < 0.0001 | 71 | 20.0 |
| 2009 / 10 | 0.468 | 0.445 | 4.01 | < 0.0001 | 67 | 18.8 |
| 2010 / 11 | 0.408 | 0.475 | 4.92 | < 0.0001 | 85 | 13.8 |

Table 3. Comparison of results obtained for questions requiring and not requiring mathematical skills in online tests and in exams during the academic years 2009-11. In brackets, percentage of mathematical questions of total number of questions, and increase factor of the percentage of blank answers in questions requiring mathematical skills with respect to not requiring ones.

| | Online tests | | Exams | |
|-------------------------|------------------|--------------|------------------|--------------|
| | Not mathematical | Mathematical | Not mathematical | Mathematical |
| Number of questions | 89 | 18 (16.8 %) | 204 | 44 (17.7 %) |
| Number of answers | 3407 | 668 | 3460 | 826 |
| Number of blank answers | 262 | 177 | 692 | 218 |
| % of blank answers | 7.7 | 26.5 (×3.3) | 20.0 | 26.4 (×1.3) |

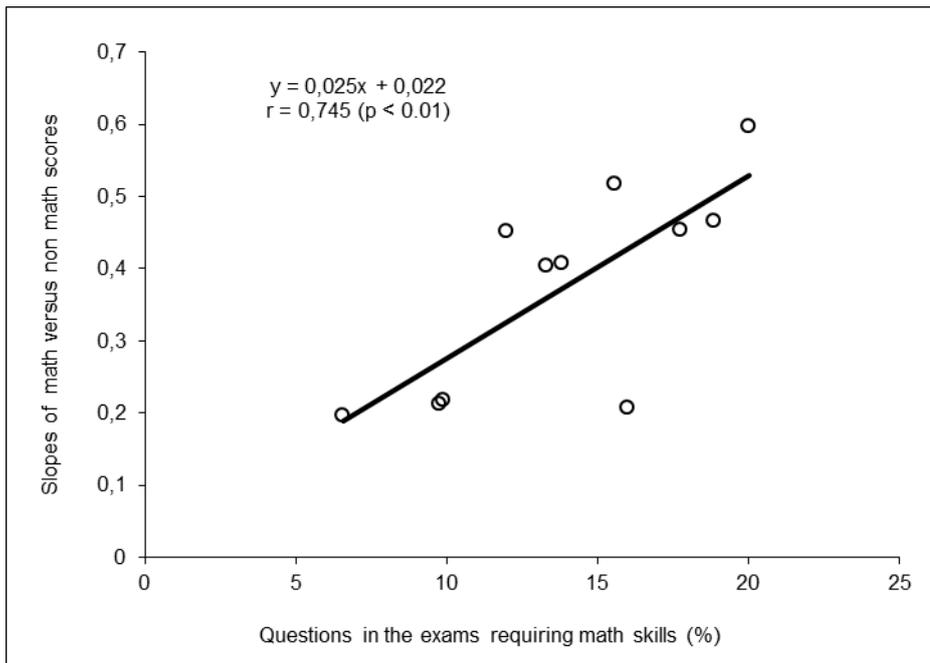


Figure 1. Relationship between correlation slopes for each academic year between scores obtained for questions requiring and not requiring mathematical skills and the percentage of questions requiring mathematical skills in the examinations.

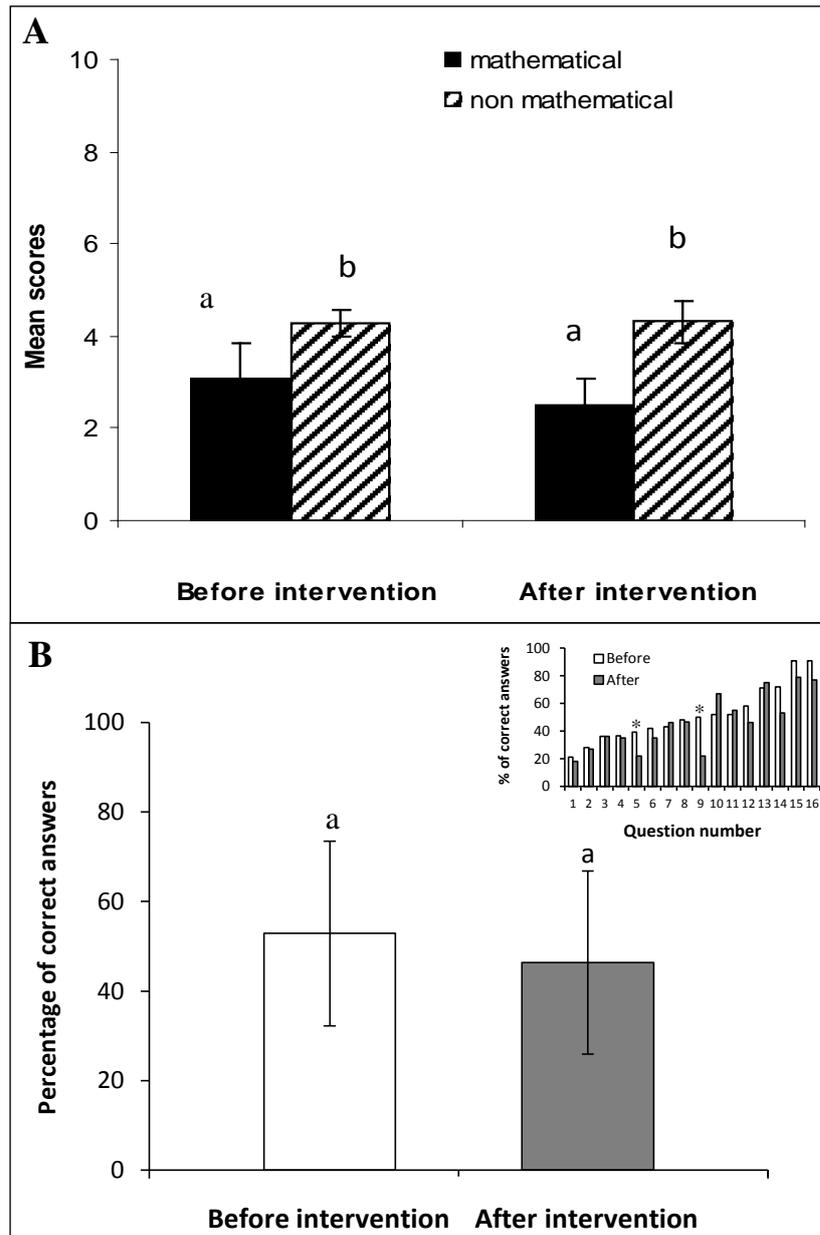


Figure 2. A - Mean scores obtained for questions requiring and not requiring mathematical skills, before (2000-2003) and after intervention 1 (2004-2011). B – Percentage of correct answers obtained for 16 questions requiring mathematical skills, included in examinations before and after intervention 1. The inset shows the results for each question, ordered from the most difficult (1) to the easiest (16). In both panels, standard deviations of the means are shown as vertical bars. Statistically significant differences ($P < 0.05$) are indicated by different letters or, in the inset, by an asterisk.

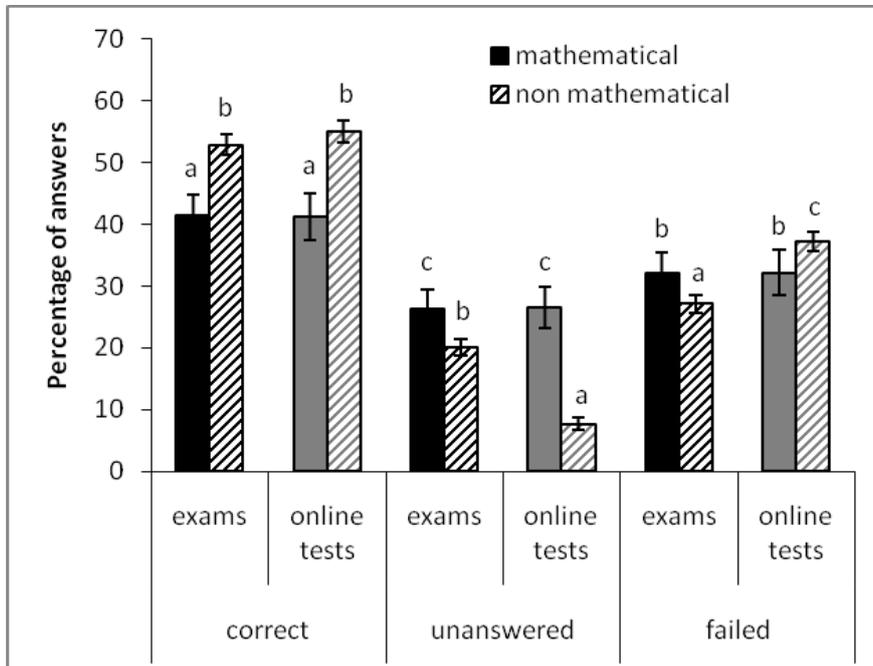


Figure 3. Comparison of results obtained in the examinations and in online tests by students of the academic years 2009-11. Within each type of response, different letters indicate significant differences ($P < 0.05$). 95 % confidence intervals are shown as vertical bars.