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Some Didactic Alternatives and Their Implications in the Learning of Set Theory Content

Algunas alternativas didácticas y sus implicaciones en el aprendizaje de contenidos de la teoría de conjuntos

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Abstract

The main purpose of this study was to explore to what extent supplementary academic aid —tutors, support sessions, parallel courses, and/or private classes— in addition to the regular class, influence students' comprehensive math performance as demonstrated on the written exams of the course Introduction to Mathematics, at the beginning of their university studies. A sample of 275 first semester students in the School of Economics and Social Science at the University of Carabobo in Venezuela was selected. Based on a non-experimental *ex post facto* statistical analysis, the results show some evidence of variation in the dimensions of math performance due to the type of academic aid used by the students to complement the course activities. Additionally, some differences were found between the traditional assessment (*math achievement*) of math content and the experimental assessment method (*math performance*).

Key words: College mathematics, mathematical logic, set theory, cognitive measurement.

Resumen

El propósito principal del estudio fue explorar en qué medida los apoyos académicos adicionales a la cátedra (tutorías, preparadurías, cursos paralelos, y/o clases particulares) influyen en el desempeño matemático integral de los estudiantes de recién ingreso a la universidad en la asignatura Introducción a la Matemática, y se evidencian en sus exámenes escritos. Se seleccionó una muestra de 275 alumnos del primer semestre de la Facultad de Ciencias Económicas y Sociales de la Universidad de Carabobo en Venezuela. Con base a un análisis estadístico no experimental *ex post facto*, los resultados muestran evidencia de variación en las dimensiones del desempeño matemático, derivado del soporte usado por los estudiantes como complemento de sus actividades de cátedra. Además, se encontraron diferencias entre la evaluación tradicional (*rendimiento matemático*) y la evaluación experimental (*desempeño matemático*).

Palabras clave: Matemática universitaria, lógica matemática, teoría de conjuntos, evaluación cognitiva.

Introduction

In Venezuela, the problem of poor academic performance in mathematics is nothing new. For decades there has been evidence that math training at all levels of the national educational system is deficient, but this inadequacy is particularly noticeable when students enter higher education. This problem has been studied from diverse perspectives and different strategies have been tested in hopes of finding a solution or at least minimizing the negative effects of a manifestly insufficient education in an area of such priority for university curriculum as math training. However, until now little has been achieved to reduce the negative indicators of student performance in this discipline (Gual and Blanco, 1997; Morales and Credes, 2004; Muñoz, 1995; Orozco and González, 1998; Sequera, 1996; Rico, 1995).

Other research papers have demonstrated that the trend toward low performance indicators in math is widespread, and that the problem impacts the student's entire university education. For example, a study by the Venezuelan Office of University Sector Planning (OPSU), points out that in a sample of 194,242 students aspiring to the higher education system, the average score on the numeracy test was 9.78 out of a total 50. Likewise, on the entrance exam the averages in math on a scale of 1 to 20 were 9.48 points, 8.68 points, 7.63 points, and 8.07 points for the years 1995, 1996,1997 and 1999, respectively (OPSU, 1998).

This phenomenon is exacerbated at the level of higher education because it is then that the accumulation of flaws and omissions committed during the previous phases of preparation—when the necessary mathematical foundation for professional training is laid—become evident. In this regard, the initial phase of university study programs contend with the consequences of a substantial paucity of basic mathematical prerequisites for the transition of students from secondary to higher education. At a higher level, the process of teaching and learning math and its applications is more complex, demanding greater commitment to achieve the efficacy of teaching activities due to the multiplicity of factors involved.

On the one hand, college professors in the first few semesters of study programs are called upon to search for teaching alternatives that would allow them to rectify the flaws detected in the precollege education. The professor feels obliged to increase the number of students who pass the course, reduce the number of failing students and dropouts as well as provide the students with a sounder mathematical foundation for the pursuit of their higher education.

On the other hand, students in the first semesters of their university career become aware that their conceptual deficiencies render them ill equipped for tackling higher mathematics and either demand solutions or recur to parallel out-of-classroom remedial alternatives that could contribute to their success as students at the university level.

Moreover, although it is conjectured that the concepts of constructivist pedagogy have made inroads in university level mathematical teaching, the focus of academic assessment in higher education continues to be obsolete. Most math professors remain attached to an evaluation based on a written exam with an emphasis on the precision of the results, procedures and operations of development problems, in true traditional style. This further complicates the situation of precollege educational gaps and presents new challenges for teaching in the initial stages of undergraduate study.

There is abundant published research that raises the issue of a discrepancy between the minimum requirements of mathematical development expected by institutions of higher education and the deficient product being offered by secondary level educational institutions (Capote, 1996; González, 1993; Orozco, 1992; Orozco and Labrador, 1997; Orozco and González, 1998; Ramos 1994; Sequera, 1996; Ramos, 2005). These papers offer evidence of the complexity of the problem and the inadequate math preparation which elementary and secondary education is providing.

An analysis of the internal statistics of the Directorate of Information and Student Control* (DICES) of the University of Carabobo shows that in some schools the number of students who graduated in the exact time-frame expected for their degree program is between 2% and 18%, with alarming dropout rates and a high percentage of students who take up to four times the normal time period to graduate. Although the phenomenon cannot be attributed solely to the field of mathematics, it is not surprising that in study majors with high math content, the situation appears worse. For example, in the School of Electrical Engineering 44% of graduates have spent up to 22 years studying before obtaining their degree while the in the School of Economics 48% of graduates have been studying at the university level for more than 10 years (Sulvaran, 2005).

In particular, according to the files of the Directorate of Information and Student Control of the School of Economics and Social Sciences** (FACES), during the first academic period of the year 2000, in the course Introduction to Mathematics, the percentage of students that failed was 62%. For the second academic period of 2001 the fail rate in this course was 67%. The first semester of 2002, 69% of students failed and during the second semester of that same year the number rose to 70%. The upward trend continued during the first academic period of 2003, with the number of failed students in the course reaching a total of 72%. As can be seen, the success rate decreased significantly, from 38% of students passing the course to 28%, a 10% drop in the success rate for the subject in just three years.

In the midst of this difficulty, in an attempt at reducing the perceived deficiencies, the School of Economics and Social Sciences of the University of Carabobo, proposed and is in the process of applying remedial plans at the institutional level. The professors teaching the university's lower-division math courses also were obliged to propose and test remedial alternatives that could satisfactorily overcome the lack of basic mathematical knowledge on the part of the high school graduates who enroll in the higher educational system. Furthermore, the students, of their own initiative, seek out remedial or preparatory mechanisms in addition to their regular university classes. Still, despite these initiatives, the negative indicators continue.

At the same time, universities at the national level have not proposed any decisive actions for solving the problem of the new students' cognitive deficiencies at its source. For example, the problem has not been addressed in secondary level

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* Translator's Note: The equivalent of the Office of the Registrar

** Translator's Note: Facultad de Ciencias Económicas y Sociales in Spanish educational institutions, nor has an avenue for informing the secondary level math sector of the deficiencies identified at the university been established, nor are there any training programs or large scale refresher courses for updating the in-service pre-university level teachers' knowledge. In their place, the field has been ceded to the private sector, which makes a business out of offering the students options such as parallel courses, texts, guidebooks, problem guides and other alternatives of dubious educational value, which have not been evaluated nor received any follow up.

Hence, it appears that the solutions being tested are aimed at alleviating the problem once the deficiencies are evident and the student is already in college. But despite the persistence of propaedeutic courses, support sessions, tutoring and other remedial proposals—both public and private—focused on enhancing mathematical thinking, these institutional or private alternatives either do not appear to be effective or have not been evaluated in depth.

In practice, the indicators seem to show that these initiatives have failed to improve the situation; in fact, all evidence would appear to support the idea that they have a counterproductive effect on the student's math development. Perhaps this adverse effect is due to the fact that these solutions are founded on the same traditions and concepts of the classic educational approach which created the problem in the first place. Possibly it is due to the fact that these options encourage the use of automatic, irreflexive "procedural shortcuts" for the type of mathematical problems found on exams, and neglect to address fundamentals, logical sequence or mathematical formality, much less the comprehension of content and the meaning that it should have for the students.

The results, figures and reflections presented in the preceding review of literature lead to the conclusion that if the current state of institutional neglect of this clearly diagnosed condition is maintained, student performance in mathematics and related fields will remain at critical levels, compromising academic productivity, as well as the prestige and efficacy of higher education.

With this in mind, one of the underlying objectives of this study is to identify the original and most elemental causes of poor math performance by examining the evidence provided by the contextual reality. To this end, we have endeavored to obtain precise, coherent and scientifically valid information that can be used for the creation of specific correctives for teaching, learning and evaluation of math content at the onset of university studies.

The formulation of the following questions was considered pertinent for guiding the research on the problem in question: What dimensions of the Introduction to Mathematics students' math performance are influenced by didactic alternatives—both in and out-of-classroom—such as introductory workshops, tutoring, parallel courses or propaedeutic courses? How much do out-of-classroom courses and other initiatives affect the math performance of the Introduction to Mathematics students? What is the relationship between the auxiliary educational alternatives and the dimensions of math performance? To what extent is there a discrepancy between the assessment of math performance and traditional math achievement?

I. Method

This research uses a non-experimental design, with an ex post facto model of four groups and a written test that underwent different assessments, taking into account various dimensions of *math achievement* and *performance*.

In addition, the context was described in terms of the general characteristics of the group of participants. For this purpose we used a survey-type questionnaire with closed-end questions, which was applied at the beginning of the study. The information from the survey allowed us to classify the students and form the four comparison groups.

For the subject of the research we selected the topic “Introduction to Set Theory”, one of the topics of Unit II of the curricular program of the course Introduction to Mathematics. This unit was chosen first of all by virtue of being the unit that results in the greatest number of failing grades in the midterm exam (Morales and Credes, 2004); secondly, as a concept which falls between the concrete and abstract; and lastly, because it is a bridge between logic and mathematical analysis.

1.1. Participants

The results of the study were obtained from a sample of 272 randomly selected freshman students who were enrolled during the first semester of 2005 in the course Introduction to Mathematics, part of the core curriculum for the bachelor’s degrees in Industrial Relations, Business Administration, Accounting and Economics in the School of Economics and Social Sciences (FACES) at the University of Carabobo.

The student sample presented a relative homogeneity in the number of students per classroom—between 50 and 60—with ages ranging from 17 to 22. Gender distribution was 43% male and 57% female. With respect to socioeconomic status, 80% of the students were middle class or lower middle class. There was also uniformity of evaluation because of the clear consensus among teachers in relation to following the course curriculum and evaluation program, which were coordinated by the department.

Still, there was a marked heterogeneity in the use of different alternative didactic aids as well as the time devoted to study of the subject, which constituted the independent variable. Thus, some students attended only the regular university class four hours a week; others, in addition to the regular class attended support sessions (two hours a week of exercises taught by the most advanced students); still others received approximately one hour of tutoring a week from the course professors to clear up any doubts; and another group availed itself of parallel private leveling programs on the subject or received assistance from private teachers averaging four hours a week. Consequently, the sample was divided into four subsamples, one for each supplementary educational alternative used by the students during the Introduction to Mathematics course.

1.2. Procedure

We asked 272 students to answer a questionnaire with closed-end questions devised by the research team. The questionnaire requested information on the student's university experience in the subject; typical study habits; time devoted to the study of the contents of Introduction to Mathematics; repetition rate (how many times the student had retaken the course); the previous educational institution (public or private); the type of alternative didactic aids used; and some personal information such as age, gender and the grade received in the first and second midterm exams for the course. With this information, we formed a body of data for a descriptive analysis of the overall sample which also allowed us to identify particular features of similarity or difference necessary for determining the inclusion or exclusion of individuals in the subsample.

The researchers then collected all of the written exams that were available (255 of the 272 tests) from the general sample and a second body of data was formed for the inferential analysis, made up of four subsamples corresponding to the alternative didactic aids used by the students to complement their study of the course Introduction to Mathematics.

Finally, we constructed a conditional random sample of 53 tests which were divided into four groups:

- 15 from students who only attended class;
- 12 from students who also took some propaedeutic course;
- 15 from students who received assistance from outside the institution; and
- 13 students who, in addition to the class, participated in the school sponsored support sessions.

In many cases, students from a particular subsample attended class and received more than two alternative teaching aids, in which case they no longer exactly matched the definition of the subsamples and were therefore eliminated from the experiment. This is the reason why the total number of exams obtained and analyzed is lower than the total number of participating students.

In addition, we constructed a rubric or rating scale to identify any evidence of constructivist learning processes in the students' answers on the written exams (second midterm). The level to which these processes were achieved was estimated using a value scale from 1 to 5, for areas such as response quality, error level, math communication level, reasoning level and the level of learning transfer of math content.

From this we obtained five partial estimates and a total assessment of math performance. Additionally, we obtained the grade received on the written exam, administered by the course professor as a measure of math achievement for the second midterm, in accordance with the traditional concept of course evaluation. Finally, we compiled the grades given by the professor in the first midterm as a reference for the student's previous academic performance.

1.3. Data analysis

The students' responses on the questionnaire were tabulated and subjected to a descriptive statistical analysis; distribution trends for the sample were established for the categories in which the participating students were classified. The main objective of this analysis was to obtain information that would allow us to subdivide the sample in independent and internally homogenous subgroups according to the different didactic options used by the students while they were taking Introduction to Mathematics. These results also allowed us to describe in relatively broad terms the socio-pedagogical context of the research subjects, as well as the internal characteristics of the written tests studied.

The written tests that were collected were organized by subsamples and were evaluated taking as the unit of analysis *the entire response to each question*. The entire response includes the dimensions of *response quality, error level, mathematical communication level, reasoning level and the degree of learning content transfer*. Additionally, there was a comprehensive assessment of math performance and the numerical grade given by the course professor on the exam was considered as a benchmark performance indicator.

Thus, to determine the performance, responses were evaluated using a rubric for each dimension, with numbers from 1 to 5 as indicators of individual math performance by dimension for each test item. In this way, the comprehensive and dimensional math performance was determined for each student on each test. These were then compared with the numerical grade given by the course professor on each student's midterm exam.

II. Results

2.1. Descriptive analysis of the assessments

The analysis of the assessments of the written exams reveals that, in general, for the total sample the comprehensive averages both of quantitative measurements as well of qualitative dimensions show little variation, although the average score received by the overall sample on the second midterm is relatively lower than the average for the first midterm. This confirms Morales and Credes' (2004) findings that it is the second midterm which produces the largest number of failures, compared with the other midterms.

With respect to the qualitative dimensions of performance—error level, mathematical communication level, reasoning level and degree of transfer—that are reflected in the exams, they hover around 12.25 (see Table I).

Table I. Distribution of the average estimates of comprehensive math performance of the total sample, by dimensions (rubric) and achievement (midterms)

Assessment	N	Score	Standard Deviation	Minimum	Maximum
Response quality	53	14.15	5.22	1	24
Error level	53	13.36	4.99	2	23
Communication level	53	12.13	4.17	1	19
Reasoning level	53	11.94	4.45	1	21
Degree of learning transfer	53	12.23	4.34	2	21
First midterm	53	10.11 (12.63)*	2.91	3.00	18.25
Second midterm	53	9.31 (11.63)*	4.02	1.25	19.00
Comprehensive performance	53	62.81 (11.90)*	21.24 8.45	7	105

* Standardizing the scales (1-25)

It is worth mentioning that the scale is 1 – 25, so the score does not reach 50%, which is equivalent to 9.8 points on the traditional scale of 1 – 20. In addition, using the scale (1-25) as a reference, the overall estimate of performance (11.90) is lower, but relatively similar in comparison with the quantitative average of the midterm exams (12.33).

These results suggest that the traditional quantitative method of grading the exams (*math achievement*), on average, produces the same results as the technique with rubrics used in this study to evaluate the written exams qualitatively, by processes (*math performance*). However, it should be noted that the evaluation of response quality and error level using rubrics shows a considerable difference from all the other estimates, including the quantitative grades on the two midterms that were analyzed.

In conclusion, from the descriptive analysis of the total sample on the written test on “Set Theory”, by dimensions (using rubrics), it can be asserted that the performance averages appear to have slight differences in comparison with the traditional quantitative assessment of the second midterm (the grade given by the professor). Also, there would appear to be a greater difference in the estimation of comprehensive performance using qualitative dimensions as compared with the quantitative assessment. That is, the average grade for the total sample on the second midterm appears to be slightly lower (see Figure 1).

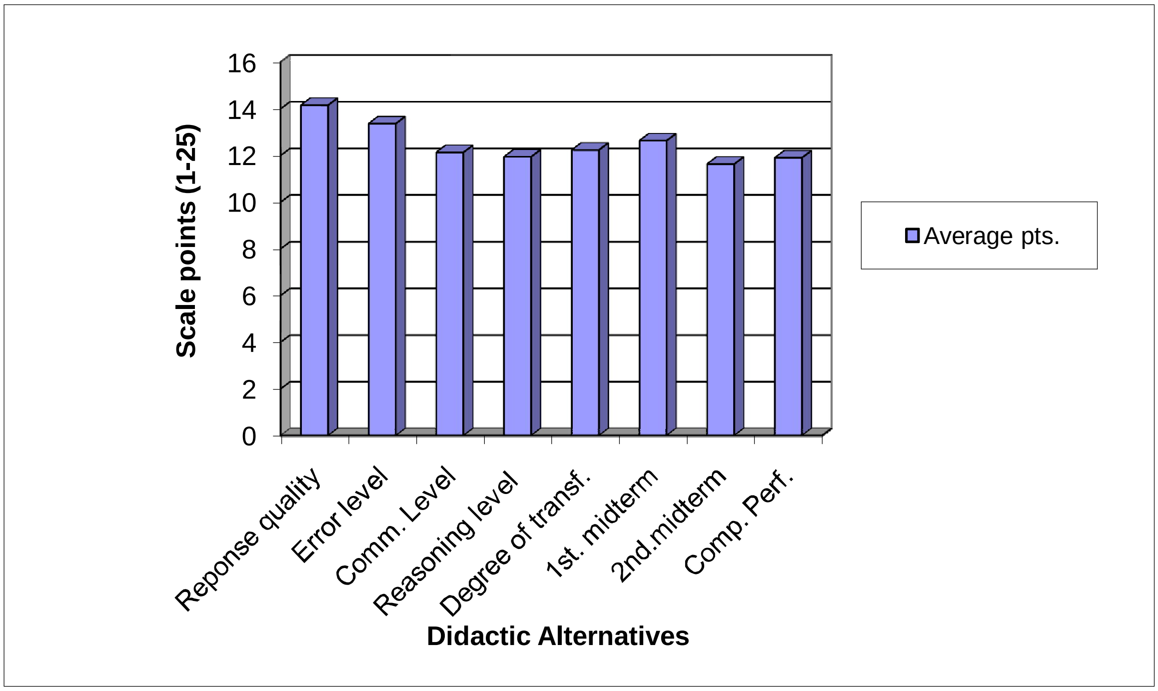

Figure 1. Averages of the math performance and achievement dimensions by alternative didactic aids of the total sample.

2.2 Description of achievement (midterms) and performance (rubrics) by alternative didactic aid subgroups

In the description of the results of *math performance* (rubrics) —by alternative didactic aid—pertaining to *math achievement* (second midterm) for the "Set Theory" content, we can observe some striking differences. For example, the average quantitative grade given by the professors on the second midterm is lower than the comprehensive assessment for overall math performance, for all four alternative educational aids. In other words, descriptively speaking, it would seem that the method used for grading math achievement (quantitative) compared with math performance (qualitative), makes a difference (see Table 2).

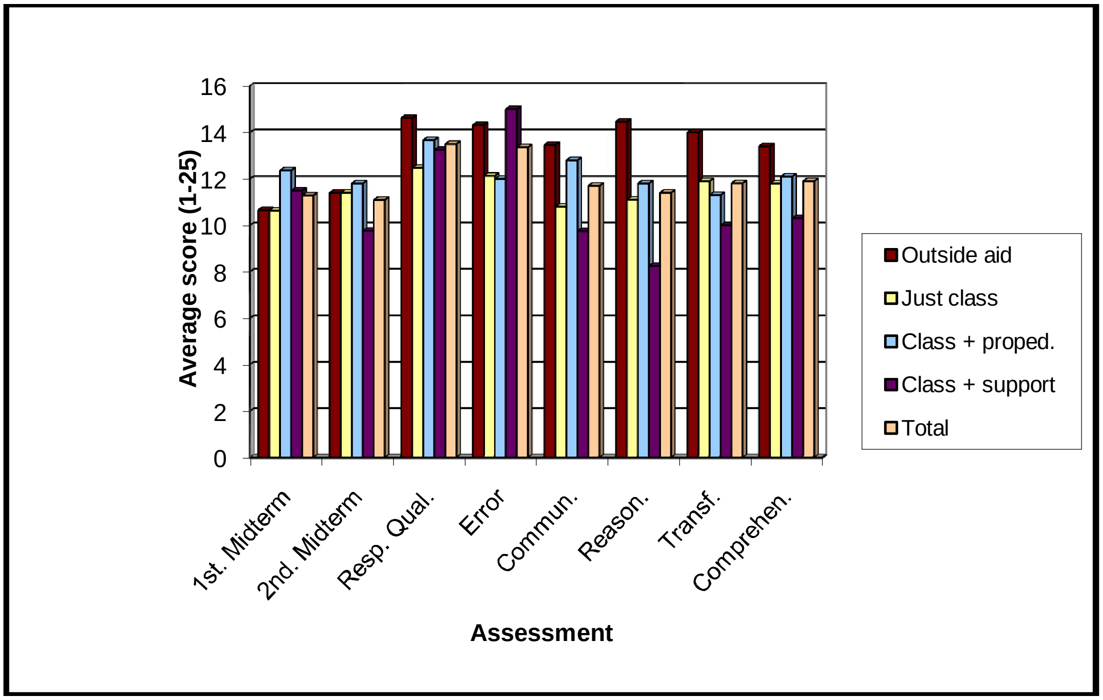

Figure 2. Evaluation of achievement and performance by alternative didactic aid

It should be mentioned that in this analysis the first midterm is only a benchmark for the initial condition of group homogeneity, particularly in formal logical reasoning. In fact, this test of mathematical logic (first midterm) reveals a relative homogeneity in all four groups in logical reasoning, with a slight difference between the group that only attended class and those that took a propaedeutic course. It would appear that, to some extent, taking a propaedeutic course enhances the students' logical-mathematical reasoning. Also, the homogeneity of the students' quantitative grade for the second midterm is striking, with the exception of the group that participated in the support sessions. Descriptively, it seems that participating in the support sessions not only negatively affects the grade in the second midterm, but also the qualitative evaluation of comprehensive performance (see Figure 2 and Table II).

Table II. Average logical-mathematical performance results, according to the performance dimensions by exam, by alternative teaching aid (homogeneous subsamples)

Alternative Teaching Aid	1st. Midterm	2nd. Midterm	Resp. Qual.	Error	Comm.	Reason.	Transf.	Compr.
Outside assist.	10.65	11.4	14.62	14.31	13.46	14.46	14.00	13.4
Class only	10.63	11.4	12.47	12.13	10.80	11.1	11.9	11.8
Class + propae.	12.36	11.8	13.67	12	12.8	11.8	11.3	12.1
Class + support	11.49	9.76	13.25	15	9.75	8.25	10	10.3
Total	11.28	11.09	13.50	13.36	11.70	11.40	11.81	11.90

Note: Scale 1-25.

With respect to the *math performance* scores, note that the students who received outside assistance (both parallel courses and private tutoring) achieved higher percentages in the dimensions of response quality (14.62), reasoning level (14.46), mathematical communication level (13.46) and degree of learning transfer (13.4). However, the level of errors was also higher (14.31) and, interestingly, the grades on the first and second midterms were not higher (see Table II).

On the other hand, the students who supplemented their attendance in class by participating in the support sessions achieved lower averages in math performance –including the average for the second midterm–, and also have the highest error level in the exam (15). This was reflected in the *comprehensive performance*, where we can observe that, although the differences are not so marked, the average obtained by the group that attended class but also received complementary outside assistance (13.4) did the best; whereas the lowest total performance average was corresponds to the group that complemented their class attendance with the support sessions (10.3). Perhaps this circumstance is due to the teaching style employed by the student coaches, which focuses on exercise practice, shortcuts and procedural recipes for solving problems mechanically, while neglecting any formal deepening on the topics and without providing any mathematical justification, an approach which could be inhibiting superior thought processes (see Table II).

2.3. Inferential analysis of the differences between the averages of the subsamples

It would appear that the preceding descriptive analysis has allowed us to corroborate the initial assumptions of this study. The first relates to the stratification of the students into different groups according to the alternative didactic aids utilized –whether singly or a combination of several–, in order to successfully complete the course Introduction to Mathematics. The second concerns the existence of a difference in the appraisal of success on the exam on set Theory content for the course Introduction to Mathematics, depending on whether the assessment is of *achievement* (quantitative grading of precise operations and procedures) or *math performance* (the assessment of reasoning processes using rubrics).

Consequently, in order to make inferences and test hypotheses, we proceeded to divide the sample of students into the four homogeneous and well-defined subgroups used in the description:

- Sample 1, those who attended class and also received outside assistance such as parallel courses or assistance from private teachers
- Sample 2, those who only attended class and received no outside assistance and had no previous experience such as precollege or propaedeutic courses.
- Sample 3, those who attended class and had previous university experience such as propaedeutic courses or studies in institutions of higher education.

- Sample 4, those who attended class and also participated in the support sessions.

From the preceding partial findings, we proceeded to explain the causal relationships of the variables involved in the study, for which an operational hypothesis was formulated, based on the working assumptions made previously. The operational hypothesis referred, in general, to the degree of significance of the differences in averages obtained by the students in the different dimensions of achievement and performance, according to the four alternative didactic aids studied.

Operational Hypothesis: Didactic aids—both in and out-of-classroom—such as parallel courses, support sessions, propaedeutic courses, tutoring, etc. have different effects on the average measurement of several dimensions of academic performance in the area of “Set Theory” of the students in the course Introduction to Mathematics of FACES, compared with the effects on the averages of these same dimensions produced by the course alone.

Statistical hypothesis: Null hypothesis (H_0).

H_0: $\mu_1 = \mu_2 = \mu_3 = \mu_4$

The null hypothesis states that there is no significant variation between the achievement and performance averages as a result of the alternative didactic aids. That is, each and every one of the complementary alternative educational aids produces significantly equivalent averages.

Alternative hypothesis (H_1): H_1: $\mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4$

The alternative hypothesis states that at least one pair of complementary alternative didactic aids produces significantly different averages in the measurement of math achievement and performance.

The inferential analysis was then performed using analysis of variance (ANOVA) of two factors and four groups (2X4), using repeated measures, according to the multiple dimensions of logical mathematical reasoning. This statistical technique allowed us to contrast the two working hypotheses with 95% confidence and thus respond to the research questions with a high degree of certainty.

However, considering that this technique provides information on significant differences in any pair of groups, but does not indicate which alternative is superior, it was necessary to perform a complementary *post hoc* procedure. We therefore selected the Tukey test to determine which of the strategies—and in what hierarchy—produce really significant effects in the achievement or performance of the “Set Theory” contents in the course Introduction to Mathematics.

The significance values greater than 0.05 in Table III, the results of the repeated measures ANOVA, indicate that there are no significant differences in the achievement averages (midterms) and the performance averages by processes (dimensions) that are derived from any of the alternative didactic aids used by the students to supplement the course. Similarly, the *post hoc* Tukey analysis, with a coefficient of significance α = 0.05, corroborated the ANOVA results, ranking the comparisons between the alternative educational aids but without giving any evidence of significant difference between the possible pairs.

Table III. Analysis of variance (ANOVA) of two factors and four groups of the estimates of math achievement and performance, according to the type of complementary alternative didactic aid used in addition to the regular class

		Sum of squares	**d.f.**	**Mean squares**	**F**	**Sig.**
First midterm	Between groups	61.931	3	20.644	2.744	0.056
	Within group	285.837	38	7.522		
	Total	347.768	41			
Second midterm	Between groups	2.460	3	0.820	0.048	0.986
	Within group	838.833	49	17.119		
	Total	841.293	52			
Quality	Between groups	96.392	3	32.131	1.192	0.322
	Within group	1320.400	49	26.947		
	Total	1416.792	52			
Error	Between groups	63.553	3	21.184	0.843	0.477
	Within group	1231.579	49	25.134		
	Total	1295.132	52	1295.132		
Communication	Between groups	50.451	3	16.817	0.965	0.417
	Within group	853.624	49	17.421		
	Total	904.075	52			
Reasoning	Between groups	109.257	3	36.419	1.941	0.135
	Within group	919.573	49	18.767		
	Total	1028.830	52			
Transfer	Between groups	56.114	3	18.705	0.991	0.405
	Within group	925.169	49	18.881		
	Total	981.283	52			
Total	Between groups	588.482	3	196.161	0.420	0.739
	Within group	22877.631	49	466.890		
	Total	23466.113	52			

Note: Analysis performed using SPSS program, version 10.0

Therefore, the null hypothesis is accepted indicating that with 95% confidence the averages obtained in the traditional evaluation of achievement and the estimate of average math performance, in all its dimensions, do not vary significantly depending on the alternative didactic aid used by the students to supplement the regular Introduction to Mathematics class.

III. Discussion

Although no significant differences were found either in the use of alternative didactic aids or the type of assessment, the results of the descriptive analysis confirm the findings of other previous studies, that coincide in presenting similar trends and figures for performance in different contexts of higher education, at different times and with very different forms of assessment (Sequera, 1996; Orozco and González, 1998; Ramos, 2005).

The existence, however, of a deficient level of precollege math preparation—both in the procedural and operational abilities we have identified as *math achievement*, as well as in the abilities and thought processes catalogued in this paper as *math performance*—has definitely been confirmed (Morales and Credes, 2004; Ramos, 2005). This may suggest the need for a transition period designed to minimize the discrepancy between precollege math and the expectations at the higher education level; to reduce omissions, errors and the negative attitudes of students; and to increase the meaningfulness of math for the students as well as their understanding of and openness to math content (Orozco and González, 1998).

Therefore, one could argue that the main problem with regard to recurring poor math performance is a persistently deficient precollege preparation, due to a mathematical pedagogy focused on exercises and the memorization of rules, standards and procedures for problem solving while neglecting to imbue said rules and exercises with any meaning or connection to the student's reality (Orozco and Morales, 2005; Ramos and Sequera, 2003).

Moreover, the remedial alternatives have no effect since they are administered using the same methods and criteria as the type of conventional teaching which caused the problem in the first place. They also apply the same type of traditional assessment as is implemented in standard courses. This contradicts the validity and relevance of the theoretical postulates of the reformist wave and the guidelines and current trends of math education and evaluation established in their theoretical framework (Latterell and Copes, 2003; National Council of Teachers of Mathematics [NCTM], 1989, 1995, 2000; Godino and Batanero, 1994; De Guzmán, 1994).

IV. Conclusions

As a general conclusion, we can say that it is unlikely that the problem of low performance in the unit "Introduction to Set Theory" in the context of this study is due to the professor or the teaching. At the very least, it does not seem feasible that it could be improved with any of the traditional complementary teaching alternatives, since none of the strategies studied in this paper produced significantly different results in the achievement or performance of the students as compared with those who attended the regular class only. Likewise, it does not appear that performance can be significantly affected by the type of learning assessment conducted in this research. In consequence, we speculate that the problem lies in deficient math preparation at the elementary and secondary educational level.

Hence, we conjecture that the poor performance detected could find an effective solution in the design of new teaching and assessment alternatives that are radically different from those that have been examined here. Nonetheless, this solution will not be potentially significant if attention and intervention are not given to the source of the problem within the precollege preparation process. This opens future possibilities and lines of research on the subject of this study, within the same field or in other disciplines and contexts where there is evidence of similar educational situations.

V. Recommendations

Further studies of this nature are recommended in order to analyze complex forms of learning assessment, to examine other mathematical content and to conduct research at precollege levels to verify the contribution of the alternative didactic aids tested in the Introduction to Mathematics course. It is also recommended that the study be replicated, refining the assessment tools to ensure greater experimental and sample control and increasing the scientific rigor of the research in order to verify or refute the findings presented here.

Furthermore, it is recommended that the analysis of the problem of low math performance in higher education be focused in other directions, such as the testing of new and radically different precollege preparatory and leveling educational alternatives. Additionally, we suggest the testing of comprehensive learning assessment systems that could fill in the gaps detected in the study, thus complementing the findings in search of an effective solution for reducing the relentless prevalence of deficiencies in students' mathematical reasoning at the onset of higher education.

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