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INTEREST IN PHYSICS, INSTRUCTIONAL STRATEGIES AND DEVELOPMENT OF PHYSICS PROBLEM SOLVING ABILITIES IN SECONDARY SCHOOL STUDENTS

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INTRODUCTION

A major goal of physics education, and indeed of all science education, is that students be able to successfully apply what they learn to problem-solving. Since learning should go beyond memorizing or paraphrasing, teachers should teach for developing problem-solving abilities. Although the former is obvious, there are few easy ways to accomplish this goal because of the many interwoven variables- cognitive, metacognitive and affective- in the learning process. Abilities and procedures tend to be implicit components of thought, amenable to reflection and active modification only by expert and mature thinkers. By making them explicit, while studying some specific content. one may provide novice physics students with powerful intellectual tools they would not likely develop on their own in a reasonable time.

This paper describes a metacognitive approach for problem solving as a mode of instruction, that could be generally useful for increasing student's problem-solving abilities whatever their interest's structure might be. A Physics curriculum (Mechanics) developed according to Ausubel's learning theory has been used specially designed for cognitive transition (Bascones, 1989, 1990).

These modes of instruction consist fundamentally of the two strategies of concept mapping and Gowin's Vee (Novak and Gowin, 1984) and relate to how the learner learns and the learner's awareness of his/her own cognitive process as their learning progresses. It has been used to study the role of metacognition in enhancing learning (Biggs, 1988) and to test how the instructional strategy involving concept mapping was effective in lowering student's anxiety towards the study of science.(Folussho et al., 1990).

Many authors have made valuable contributions for improving the process of problem-solving (Garret, 1986). Very few of these studies, however, attempted to develop particular instructional programs in response to problem-solving deficiencies detected in preliminary investigations. We have tried to make use of their findings and to avoid these shortcomings.

The metacognitive approach to problem-solving (MAPS) have been formulated in very general terms and is-with minor adaptation -applicable to problem-solving in many fields of Physics. In a systematic way, this approach lists the actions and methods, using the Gowin's Vee as a guideline that should be executed in solving problems in physics. Concurrently, the plan of instruction -moving from the more inclusive ideas to more specific ones- appears to be a good model for instruction in other fields as well.

A BRIEF OUTLINE OF MAPS

Simultaneously with the instruction for concept attainment, cognitive transition and development abilities for concept mapping, instruction was designed for enhancing the problem-solving abilities according to a synthesis of Polya´s phases for problem-solving and Gowin's Vee. Table 1 shows the schema followed during instruction.

TABLE 1

INSTRUCTIONAL SCHEMA FOR ENHANCING STUDENT'S PROBLEM-SOLVING ABILITIES

1. Analysis of the problem.
    1.1. Reading for understanding.
        1.1.1. Making explicit the telling question.
        1.1.2. Making a graph of the event(s).
        1.1.3. Identifying the context of the problem.
        1.1.4. Identifying the data as concepts (symbols, units, SR, magnitude, etc.).
        1.1.5. Identifying the unknown variables.

    1.2. Conceptual scheme.
        1.2.1. Drawing a conceptual map of the topics.
        1.2.2. Writing down relationships which follow from data, directly and indirectly.

    1.3. Transformation.
        1.3.1. Of the data (all units in IS).
        1.3.2. Transformation of the original graph into a scheme (free body diagrams, collision diagrams, etc.). All data should be mentioned in correct magnitudes (symbols and units).

4. Planning the solution.
    4.1. Establishing whether the problem is analogous to any other that has been solved before.

    4.2. Analyzing if the problem can be solved whether dividing the problem in subproblems or by working backwards.

    4.3. Trying to interrelate unknown variables with data by applying the concept map to the problem situation. If it is not possible, then restating the problem or considering it from a different point of view, if necessary (different SR, different conceptual scheme, etc.).

5. Solving the problem.
    5.1. Checking systematically if the results make sense, by analyzing the procedure and the routine operation.

6. Evaluating the results.
    6.1. Checking if the knowledge claim is the correct answer for the question asked, according to the conceptual scheme.

    6.2. Looking back at the way the problem has been solved to know more about his/her cognitive abilities.

PURPOSE OF THE STUDY

While the search for the promotion of meaningful learning through metacognition continues to receive attention, there are some other variables that might hamper the functioning of a pupil in physics problem-solving. We are concerned specifically with student's interest and some personality traits associated to concept formation in problem-solving situations (Rapaport, D., 1965). Nevertheless, concept mapping and Gowin's Vee are two strategies that are basically concerned with students learning how to learn, and understanding how the new knowledge is linked to the old one in order to be able to analyze new situations (Novak et al, 1983). Therefore it can be hypothesized that there is no difference in the trends exhibit in solving physics problems for students with different interest structures if they are taught through those strategies. On the other hand, viewing problem-solving as a kind of meaningful learning, it can also be hypothesized that problem-solving abilities could be enhanced if metacognitive strategies are used in the classroom. This is supported by the findings of Novak (1990) and Obebukola and Jegede (1988), which state that meaningful learning results through the use of concept map strategies.

The specific research questions investigated were the following:

1. Which of the following variables are predictors of the enhancement of physics problem ability: a) concept formation in problem-solving situations; b) previous knowledge in Physics and c) previous knowledge in Mathematics.
2. Are there significant differences in the trends exhibited in solving physics problems for students with different interest structures?.
3. Did the use of the metacognitive approach to problem-solving enhance the physics problem-solving abilities of students?

DESIGN OF THE STUDY

Sample

The sample consists of 32, 10th grade students in one section of a technical secondary school in Maracay, Venezuela. None of them had any prior knowledge regarding use of the MAPS. Although the school itself is coeducational, the sample consists mostly of males because very few females were pursuing technical education as an option for their secondary school. Although all of them have studied a one year course in Physics, their Physics background is quite poor according to their performance in a pretest.

Instructional Materials

Since there were no commercially available instructional materials which would fit our curricular model, we developed our own materials (Bascones and Castillo, 1993)[1]. They consisted of three

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[1] To be published early in 1994.

complementary booklets suited for use in the study because the underlying design organized the content according to Ausubel learning theory (Ausubel et. al, 1968) integrating laboratory work, instruction for conceptual change and problem-solving activities. Table 2 shows the core physics concepts encompassed by lessons 1-48 of the program used in the study.

TABLE 2

RANGE OF PHYSICS CONTENT TAUGHT USING THE MAPS

A. The structure of physics.
B. Measurement.
C. The language of Physics.
D. Concept mapping and Gowin's Vee.
E. States of movement.
F. Basic concepts of Mechanics.
G. Reference frames.
H. Newton's Laws.
I. Friction.
J. Dynamics of one dimentional motion.
K. Dynamics of two dimensional motion.
L. System of interacting particles. Center of mass and reference frames.

Definition of Terms

Interest: Desire to learn or know more about some kind of events, activities, facts or anything related to them.

Problem-solving Ability: Capacity to reorganize the cognitive representation of prior experience and the components of a current problem situation in order to achieve a designated objective.

Concept Formation in Problem Solving Situation (CFPSS): Process of abstracting the essential common features of a class of objects that vary contextually in a problem solving situation. According to Ausubel there are some personality traits which influence problem solving abilities.

Personality trait: Some hypothesized underlying disposition or characteristic of a person that, in principle, can be used as an explanation of the regularities and consistencies of behavior. We were dealing with the followings:

i) Flexibility: Tendency to modify the cognitive structure as experience is acquired. Freedom to move from one concept to another without rejecting the old one. Facility to operate with more than one concept.

ii) Persistence: to keep, in order to be used, all the concepts the individual had already acquired, without being strongly attached to any of them.

Instruments

Interest: The instrument for measuring the student's interest structure was adapted (Bascones and Villasmil, 1991) from the one developed at the I.P.N Kiel, Germany (Haussler,1984). A 72-item test was divided in 6 subtests, according to 6 different topics: Optics, Acoustics, Heat, Mechanics, Electromagnetism, and Modern Physics. Each subtest, measuring interest in each topic consisted of a four item subscale: a) Interest in learning more about Physics as science, b) Interest in the technological applications of Physics and c) Interest in the impact of Physics in society.

Concept Formation in Problem Solving Situation (CFPSS): The Hansman-Kasini test, adapted in Venezuela by Alvarez, M., Universidad Pedagógica Experimental Libertador. It consisted of 22 geometrical figures of 5 different colors, 6 different forms, 2 different widths and two different hights. Subjects should classify them in four group according to some criteria that should be established by themselves in a 15 minute time period. Table 3 describes the 1-9 point scale used for evaluation.

TABLE 3

POINTS ASSIGNED TO THE SOLUTION OF THE HANSMAN-KASINI TEST

Points	Solution
1	No solution at all.
2	Any logical solution attempt.
3	Find one group out of four.
4	Find two groups out of four.
5	Find three groups out of four.
6	Find the solution.

Additional points were gained if the correct solution was found in the following time range:

Time interval (min.)	Additional points
1-5	3
6-10	2
10-15	1

Problem solving ability: It was measured by four tests (PS1, PS2, PS3, PS4) each of them assessing the student's problem solving abilities for solving physics problem. Each test, covering different contents, consisted of three (3) problems (1,2,3), with different levels of difficulty (L.D.). Each test was given in sequence, every two weeks. Table 4 shows the Physics content covered by each test and Table 5, the criteria followed to classify the problem's level of difficulty.

TABLE 4

CONTENT COVERED IN EACH TEST

TEST	PHYSICS CONTENT
PS1	The structure of Physics. Measurement. The language of Physics. Concept mapping and Gowin's Vee.
PS2	States of movement. Basic concepts of Mechanics.
PS3	Reference frames. Newton's laws. Friction.
PS4	Dynamics of one and two dimensional motion. System of interacting particles. Center of mass and reference frames.

TABLE 5

THE CRITERIA FOLLOWED TO CLARIFY THE PROBLEM'S LEVEL OF DIFFICULTY

Type of Problem(D.L.)	Criteria
1	Can be solved by direct application of an algorithm. It demands from the students to recognize the unknown variables and the ability to find its relationship with the data. It should also determine the problems context.
2	In order to be solved, this type of problem should be subdivided in linked subproblems. The solution from one of them is completely required in order to solve the next one. It demands from the student: i) to relate some pieces of knowledge to find new knowledge, ii) Transform the original graph into a scheme.
3	Problems in this category are unfamiliar to the students. It demands from them to use all the abilities implicit in Table 1.

Cluster Formation

A "k means" cluster analysis was used to analyze the 32 students means for the 72 variables arriving to two clusters of students based on the similarities and differences between the student's answers on the 72 variables. Figure 1 shows the means of the student's interest, by clusters, in the three subscales (dimensions): a) Interest in physics as science, b) Interest in physics as it relates to technological applications and c) Interest in physics as it relates to its impact upon society.

Cluster 1 includes those students who have a moderate to high interest in Physics in all three subscales (dimensions).

Cluster 2 includes those students who have a low interest in Physics, as a science and as it relates to its impact upon society; and by those students who have a high interest in Physics as it relates to its technological applications.

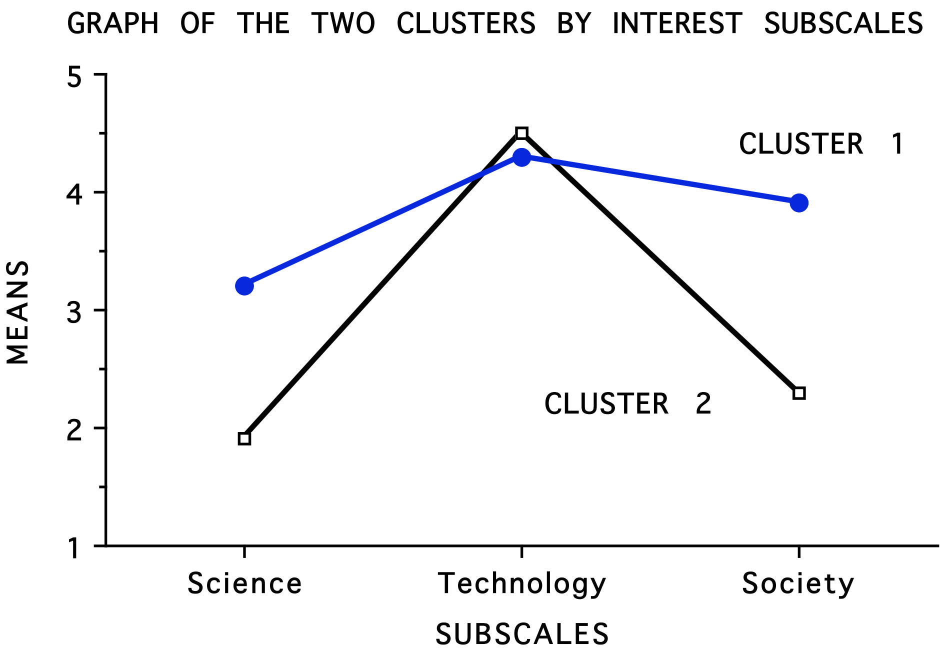

FIGURE 1

Administrative Procedures

All subjects completed core concept materials (See Table 2) during 3 months in a 9 month school year. During the first three weeks, presentation and discussion of concept mapping and Gowin's Vee for problem solving (either in the lab or as classroom activities) required about 60% of each weekly meeting period and, during the other 9 weeks, 30% of each period. A Physics and a Math pretest, an interest questionnaire and a trait personality test were administered at the beginning of the school year. A test for assessing problem solving abilities was administered in sequence every 2 weeks. All statistical analyses were conducted using software modules for the Macintosh version of SYSTAT and SPSS statistical computer packages.

RESULTS AND DISCUSSION

Reliability of the Instruments

The reliability of the Interest instrument was determined by internal consistency procedures (Cronbach's Alpha). For the Mathematics and Physics pretest instruments, test/retest procedures were employed. Table 6 shows the reliability coefficients of the three instruments.

TABLE 6

RELIABILITY COEFFICIENTS BY INSTRUMENT

INSTRUMENT	PROCEDURE	RELIABILITY COEFFICIENT	N
Interest	Cronbach's Alpha	.96	32
Mathematics	Test/Retest	.39	32*
Physics	Test/Retest	.58	32*

* The scale score is obtained by adding the scores on the 20 knowledge items of each instrument.

Descriptive Statistics

Table 7 shows the means and standard deviations of each test.

TABLE 7

MEANS AND STANDARD DEVIATIONS OF THE TESTS

TEST	M	SD	TEST	M	SD
Math Pretest*	3.97	1.64	P31	1.00	.00
Physics Pretest*	6.19	1.75	P32	.38	.49
Math. Retest	4.13	1.90	P33	.06	.25
Physics Retest	6.19	2.01	P41	1.00	.00
CFPSS	5.72	1.61	P42	.47	.51
P11** .69	.47	P43	.19	.40	
P12	.03	.18	PS1***	.72	.52
P13	.00	.00	PS2	1.06	.67
P21	.81	.40	PS3	1.44	.56
P22	.25	.44	PS4	1.66	.79
P23	.00	.00			

* Math and Physics pretests, each have a scale 0-20.
** Item scale: 0-1, for problems P11 to P43.
*** Item scale: 0-3, for tests PS1 to PS4.

Starting from the second test (PS2), the students acquired the necessary abilities to solve problems of difficulty level 1. This trend was maintained through the application of the last test.

For problems of level of difficulty 2, and between the application of the first (PS1) and second (PS2) test, there is a significant improvement of the abilities needed to solve these types of problems, and the enhancement of the abilities already acquired. This improvement persists from the second test, but the tendency is less steep.

It was only starting with the third test (PS3) that the students began to improve there performance on problems of difficulty level 3. It seems that an intellectual "warm-up" period was needed for the students to reach a "minimum" to start solving problems at this level of difficulty. This result should not be considered unusual, since the abilities to solve Physics problems are linked in the student's cognitive structure, making it more functional, as more knowledge is acquired. Some of these results, were found in previous studies (Bascones & Novak, 1986). Figures 2 and 3 show the mean results for each problem and the mean results for each test.

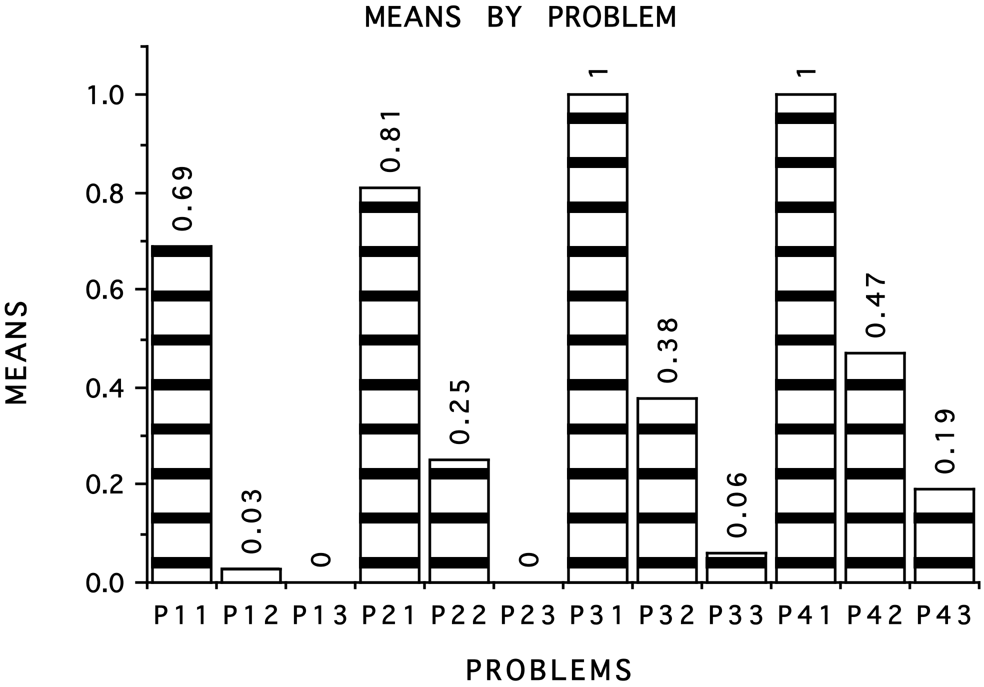

FIGURE 2

Figure 3 shows a linear trend in the performance level of the students on each test. This confirms that, in general, the instructional strategy used, has developed an adequate cognitive structure in the students which helps them improve their performance in solving Physics problems.

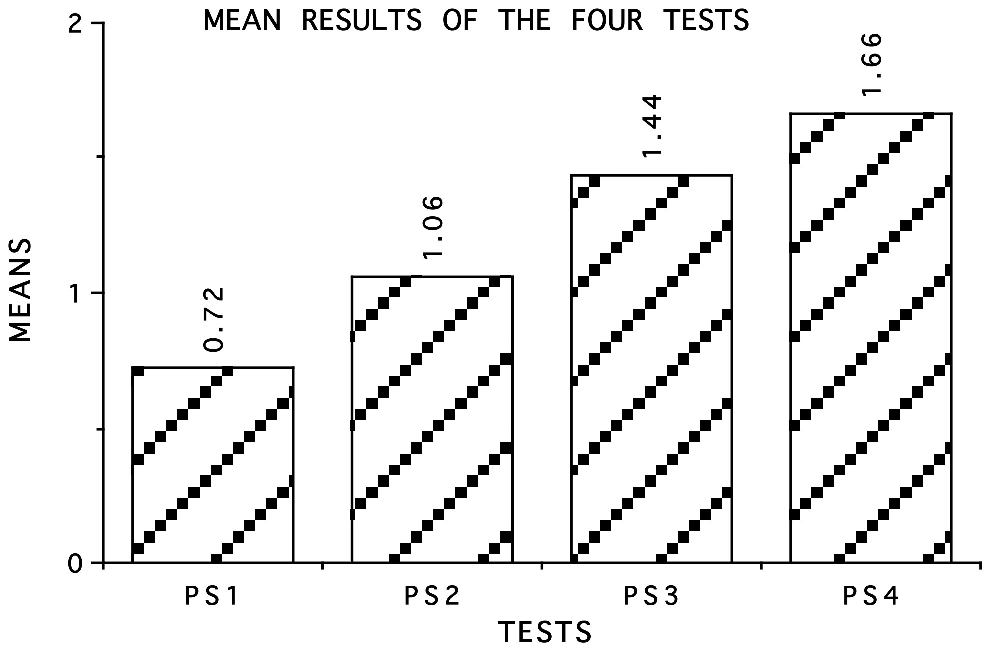

FIGURE 3

Relationships Between Variables

A stepwise regression statistical procedure was used to determine which of the following variables were predictors of the enhancement of physics problem ability (PS4): a) concept formation in problem solving situation; b) previous knowledge in Physics and c) previous knowledge in Mathematics. PS4 was chosen as the dependent variable for the analysis of the predictor variables of Physics problem solving abilities because it was the last test applied, which represented the summary, from a conceptual point of view, of all the Mechanics content studied. Table 8 shows the summary of the results for the significant predictors selected by the stepwise procedure. Table 9 shows the correlations among the variables included in the Regression Analysis.

TABLE 8

SUMMARY OF THE REGRESSION ANALYSIS SHOWING PERCENT OF UNIQUE VARIANCE ATTRIBUTABLE TO THE SIGNIFICANT PREDICTORS SELECTED BY THE STEPWISE PROCEDURE.

STEP	VARIABLE	R	R^2	β	F	$(\Delta R^2)^a$
1	CFPSS	.65	.42	.65	21.73*	
2	Physics Pretest	.76	.57	.40	19.52*	.15

* $p < .000$

^{a} ΔR^2 = The squared semipartial correlation.

TABLE 9

CORRELATIONS AMONG THE VARIABLES INCLUDED IN THE REGRESSION ANALYSIS

	Math. Pretest	Physics Pretest	CFPSS	PS4	
				Math. Pretest	1.00
	.49	.28	.42		
Physics Pretest	.49	1.00	.16	.49	
CEPSS	.28	.16	1.00	.65	
PS4	.42	.49	.65	1.00	

The fact that the Math pretest was not selected in the stepwise regression procedure as a significant predictor of Physics problem solving abilities may be due to the content that was being measured by the instrument. Of the 20 items included in the Math pretest, 80% of them measured numerical abilities, which was not needed to serve as anchorage to the new abilities for solving Physics problems.

Test of Hypotheses

Multivariate Analysis of Variance statistical procedures were used to analyze hypotheses 2 and 3.

Multivariate analysis of variance and follow-up procedures for data analyzed by clusters.

Analysis conducted on the PS1 to PS4 tests as dependent variables yielded a non-significant multivariate result. These results are shown in Table 10. Table 11 shows the means and standard deviations of the four tests by clusters.

TABLE 10

MULTIVARIATE ANALYSIS OF VARIANCE, TESTS OF SIGNIFICANCE AND FOLLOW-UP PROCEDURES FOR THE TWO INTEREST CLUSTER GROUPS ON THE FOUR TESTS MAKING A CONTRIBUTION TO DIFFERENCES AMONG THE CLUSTERS

MULTIV. TEST	VALUE	EXACT F	df	HYPOTHESIS df	ERROR	p

Wilks' Lambda .811

	1.54	4.00	27.00	.220

Univariate with (1,30) df

TEST		
PS1	3.97	.055
PS2	4.55	.041
PS3	2.14	.154
PS4	4.67	.039

These non-significant results, which relate to the enhancement of Physics problem solving abilities among the two clusters may indicate that the instructional strategy implemented, seems to overcome the problems associated with the lack of interest in Physics as a science and its technological impact upon society.

TABLE 11

MEANS AND STANDARD DEVIATIONS OF THE PS1 TO PS4 TESTS MAKING A CONTRIBUTION TO DIFFERENCES AMONG INTEREST CLUSTERS

	CLUSTERS					
	1 (N=23)		2 (N=9)		TOTAL (N=32)	
TEST	M	SD	M	SD	M	SD
PS1	.61	.50	1.00	.50	.72	.52
PS2*	.91	.67	1.44	.53	1.06	.67
PS3	1.35	.57	1.67	.50	1.44	.56
PS4*	1.48	.67	2.11	.93	1.66	.79

$p < .05$

Multivariate analysis of variance of data for the analysis of trends as a multivariate profile

Summary data for the four tests, PS1 to PS4 as repeated measures of problem solving abilities in Physics is given in Table 12.

TABLE 12

MULTIVARIATE REPEATED MEASURES ANALYSIS FOR THE FOUR TESTS, PS1 TO PS4

MULTIV. TEST	VALUE	EXACT F	HYPOTHESIS df	ERROR df	p
Wilks' Lambda	.309	21.60	3	29	.000

Univariate Repeated Measures

F-test with (3, 93) df	30.77	.000
Degrees for Polynomial Contrasts		
Degree		
1	58.98	.000
2	1.00	.325
3	.42	.521

The linear trend appears to be the only trend that is significantlly different from zero (0).

It seems that as the knowledge of Mechanics increases, it becomes more structured, and the students acquire experience through practice in problem solving, the ability to solve new Physics problems also progressively increases.

Comparisons using multivariate procedures were also made to find if there were overall significant increments in the abilities to solve Physics problems between adyacent periods (two weeks). Table 13 summarizes these results.

TABLE 13

MULTIVARIATE PROFILE ANALYSIS USING DIFFERENCE CONTRASTS FOR THE FOUR TESTS, PS1 TO PS4.

MULTIV. TEST	VALUE	EXACT F	HYPOTHESIS df	ERROR df	p
Wilks' Lambda	.309	21.60	3	29	.000
Univariate F-test with (1, 31) df					
Adjacent Periods					
1		16.24			.000
2		12.13			.002
3		6.36			.017

It seems that there was a significant increment of the students overall problem solving abilities among adjacent periods.

Conclusions

The research reported here has allowed us to develop a preliminary understanding of the effect of metacognition instructional strategies on the student's physics problem solving performance in spite of their interest structure. It also provides us with some cues about other factors that might hamper their problem solving abilities.

We believe that these finding are sufficiently important to be taken into consideration in the design and planning of learning experiences and teacher intervention.

Acknowledgments

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