Teaching-Learning through innovative experiments: An investigation of students' responses

Umapati Pattar[1], Vijay H. Raybagkar[2] and Suresh Garg[3]
[1] *Department of Physics, Vijayanagar College, Hospet, Karnataka, India.*
[2] *Principal, SSR Science, Commerce, and Arts College, Silvasa, India.*
[3] *Professor, School of Sciences, IGNOU, New Delhi, India.*

E-mail: umapati.pattar@gmail.com

(Received 5 May 2012, accepted 16 September 2012)

Abstract
The primary objective of performing a physics experiment is to gain procedural as well as conceptual understanding. Some of the researches reported in Physics Education emphasize the importance of introducing innovations in physics experiments so as to improve clarity as well as the depth of learning experiences. In this paper, we report the impact of seven experiments designed in different branches of physics and systematically tried on college students. We observe a significant enhancement in the conceptual understanding of the students after exposure to the treatment.

Keywords: Innovative experiments, Posttest, Solomon four group analysis.

Resumen
El principal objetivo de llevar a cabo un experimento de Física es obtener un procedimiento, así como el entendimiento conceptual. Algunas de las investigaciones reportadas en la Enseñanza de la Física hacen hincapié en la importancia de introducir innovaciones en los experimentos de Física con el fin de mejorar la claridad así como la profundidad de las experiencias de aprendizaje. En este trabajo, informamos el impacto de los siete experimentos diseñados en diferentes ramas de la Física y tratados sistemáticamente en los estudiantes universitarios. Observamos un mejoramiento significativo en la comprensión conceptual de los estudiantes después de la exposición al tratamiento.

Palabras clave: Experimentos innovadores, Postest, Análisis del cuarto grupo Salomón.

PACS: 01.40.-d, 01.50.Pa, 01.30.-y **ISSN 1870-9095**

I. INTRODUCTION

Traditionally, laboratory work has been incorporated in the curricula of various science and engineering courses to enrich teaching-learning experiences [1]. The reasons for doing so are many and varied. Some of the prime reasons include:

- To acquire hands-on skills and experience in the use of materials, scientific instruments and laboratory equipment; say–microscopes for biology, pipettes for chemistry and design of circuits for physics;
- To develop an understanding of the concepts and content taught in theory courses;
- To gain experience in scientific method;
- To learn how to write clear and concise reports on investigations;
- To apply scientific knowledge and methods to manipulate dysfunctional components;
- To design new experiments and/or fabricate new equipment; and
- To appreciate the ways in which scientists work.

These and such other justifications are embedded in the objectives of most laboratory programmes. General goals of science laboratories are outlined in studies reported in [2, 3, 4]. The physics-oriented perspectives on goals of undergraduate laboratories are discussed in [5, 6]. Agrest [7] highlighted the importance of innovation in physics experiments as, "*In my opinion it is important to bring some 'flavor' into studies, some dramatic experience to spice up the meal for students' brains. Often, in the course of a traditionally run lab, students perform numerous observations and measurements but leave the analysis of the results for the lab report, which may not be completed until long after class. In that case, they may not experience the emotional satisfaction associated with their accomplishments in the lab. Most lab manuals provide students with a more or less detailed description of the experiment in order to increase the effectiveness of the time spent in the laboratory. This leads to a one-dimensional flow of the experiment, and alternative approaches may not occur to students".*

The logical questions that arise for realization of this philosophy in the context of physics are: How is an actual laboratory conducted? What skills are being developed in a laboratory course? Could any of the skills be developed outside the expensive laboratory environment? How well is the laboratory time utilized? Against this background, we undertook a research study to look into the level of conceptual understanding developed through traditional laboratories (Phase-1). Subsequently, we designed a few innovative experiments in different branches of physics and conducted them on the students to assess their effectiveness (Phase-2). The findings of phase-1 were reported recently [8]. In this paper, we report the outcome of phase-2.

The Method

In phase-1, we conducted a survey on a large sample of college students during August-September of 2009 to evaluate the procedural (or conceptual?) understanding on laboratory teaching. Two tools consisting of objective type questions were developed and administered to about 500 students from 14 colleges to assess the effectiveness of physics teaching through traditional laboratory experiments. The findings of the item analysis were used to design innovative experiments, particularly to seek answers for the following two research questions:

Q1. What is the existing level of understanding of the concepts and/or theory underlying a physics experiment?

Q2. Which concepts are perceived hard on which designing innovative experiments will help improve student's learning?

A part of the data collected during the survey was also used as pre-test data. The research process has been conceptualized using the framework described by [9, 10]. The theoretical perspective of our study is post-positivism whereby we explore student experiences of experimental laboratories in a quantitative manner [11]. The chosen study design is truly experimental within an authentic educational setting. The data collected is quantitative and we use statistical analysis using suitable computer software for speedy yet reliable results.

A. The sample description

Physics is studied as one of the three optional subjects of equal weightage in B.Sc programme at Gulbarga University, Gulbarga, in Karnataka State of India. The programme is spread over three years (6 semesters).

Each semester consists of a minimum of 24 hours of laboratory work. The innovative experiments were conducted on the students of 7 colleges across the geographical jurisdiction of Gulbarga University, Gulbarga (Table I). The sample-1 was the subset of the sample used in the survey during the first phase of the study and the students had completed four semester laboratory course of B.Sc. physics. Students of sample-2 did not participate in the pretest (As they were newly admitted to the course and hence were excluded) and had completed only two semester laboratory course of B.Sc. physics. The innovative experiments developed by the researchers were conducted on the students during August-September 2010. In order to facilitate analysis, four groups with equal strength were made.

TABLE I. Sample used for conducting experiments.

Name of the College	**Pretested (Sample-1) Third year B.Sc.**		**Un-Pretested (Sample-2) Second year B.Sc.**	
	Expt Group	Control Group	Expt Group	Control Group
Vijayanagar College, Hospet (T[1]).	35	35	35	35
Channabasaveshwar College, Bhalki (R).	14	14	14	14
Kottureshwar College, Kotturu (R).	25	25	25	25
Sharanabasaveshwar College, Gulbarga (U).	30	30	30	30
Karnataka College, Bidar (U).	25	25	25	25
Veerasaiva College, Bellary (U).	15	15	15	15
Laxmi Venkatesh Desai College, Raichur (U)	17	17	17	17
Total	**Group 1 161**	**Group 2 161**	**Group 3 161**	**Group 4 161**
	322		**322**	

B. The design description

Table II shows three research designs possible with the single treatment experimental method of research. It shows Solomon four group design used by us as well as the pre- and post-test control group design and the post-test only control group design.

Each of these designs is adequate to assess the effect of the treatment and is immune from most threats to internal validity. The Solomon four-group design, has been preferred over the other two since it is the only one of the three designs that can assess the presence of *pretest*

[1] Letters in the bracket represent: T-Taluka, R- Rural, U- Urban.

sensitization. Pretest sensitization means that "exposure to the pretest increases or decreases the Samples'Sensitivity to the experimental treatment, thus questioning the validity of generalization of results from the pretested sample to an un-Pretested population" [12]. Thus, the Solomon four-group design adds a higher degree of external validity in addition to its internal validity, and hence, according to Helmstadter, it is "the most desirable of all the basic experimental designs" [13].

TABLE II. Three One-Treatment Condition Experimental Designs.

Design	Group		Pre-test	Treatment	Post-test
Solomon Four Group	1	R	O_1	X	O_2
	2	R	O_3		O_4
	3	R		X	O_5
	4	R			O_6
Pre and Posttest control group	1	R	O_1	X	O_2
	2	R	O_3		O_4
Posttest only control group	1	R		X	O_5
	2	R			O_6

Note O = outcome measure; X = treatment;
R = randomization.

In the initial phase of the analysis, we determined whether or not the evidence of pretest sensitization existed. That is, whether *X* affects O only when a pretest measure is administered. If this were the case O_2 should be higher than 0_4 (otherwise it would mean that the treatment and pretest are working incoherently), but O_5 should not be higher than O_6. (O_5 higher than O_6 would suggest a negative impact of pretest).

The test for this is a 2×2 between-groups analysis of variance (ANOVA) on the four posttest scores, as indicated in Table III.

TABLE III. 2X2 Analysis of posttest scores.

Pretest	Treatment X	
	Yes	No
Yes	Group-1(O_2)	Group-2(O_4)
No	Group-3(O_5)	Group-4(O_6)

The factors are treatment (yes vs. no) and pretest (yes vs. no). Evidence demonstrating pretest sensitization is detected by the interaction effect. An interaction effect is said to exist when the effect of one independent variable on the dependent variable changes depending on the level of another independent variable. In addition, there should be a significant ***main effect*** for treatment in the first row but not in the second. A "main effect" is the effect of one of the independent variables on the dependent variable, ignoring the effects of all other independent variables. If the preceding pattern is present, the analysis terminates with the conclusion that there is evidence of a treatment effect, but it occurs only for pretested groups; there is thus pretest sensitization (a result unlikely to be welcomed by the investigator). Huck and Sandler (1973) modified Campbell and Stanley's (1963) analysis by noting that if the main effect in the second row is also significant, there is evidence that pretest sensitization is present but that merely *enhances* the effect of the treatment, which is detectable as well even in an un-Pretested sample. If the interaction is not significant, however, we conclude there is no evidence of pretest sensitization. Is there a *treatment effect*, however? One answer to that question, suggested by Campbell and Stanley (1963) [14] is found by looking at the main effect for treatment in the above analysis. If significant, there is unqualified evidence of the treatment effect [15]. The analysis of variance is an effective way to determine whether the means of more than two samples are too different to attribute to sampling error. It would be possible to use a number of *t* tests to determine the significance of the difference between the means, two at a time, but it would involve a number of separate tests. ANOVA makes it possible to determine with a single test. Another advantage lies in the fact that computing a number of separate t tests will increase the overall Type I error rate for the experiment.

C. ANOVA

The analysis of variance consists of:

i. The variance of the scores for four groups is combined into one composite group known as the *total group variance* (V_t).
ii. The mean value of the variances of each of the four groups, computed separately, is known as the *within-group variance* (V_w).
iii. The difference between the total group variance and the within-group variance is known as the *between-group variance* (V_t-V_w=V_b).
iv. The *F* ratio is computed

$$F=\frac{V_b}{V_w}=\frac{(between-group\ variance)}{(within-group\ variance)}.$$

The logic of the *F* ratio is: The within-groups variances represent the sampling error in the distributions and is also referred to as the error variance or residual. The between-group variance represents the influence of the variable of interest or the experimental variable. If the between-groups variance is not substantially greater than the within-groups variance, the researcher would conclude that the difference between the means is probably only a reflection of sampling error. If the F ratio were substantially greater than 1, it would seem that the ratio of the between-groups variance and the within-groups variance was probably too great to attribute to sampling error [16].

II. DEVELOPMENT OF INNOVATIVE EXPERIMENTS

Based on the pattern that emerged from the survey, and since the population of interest included students who had completed the first year B.Sc. experimental course, we designed seven experiments on those topics which were already taught to the students during their first year of B.Sc.course. To assess the effectiveness of the innovative experiments a posttest was designed. Posttest consisted of thirty one multiple choice questions based on the experiments. (Details of experiments and posttest can be had from the auther[1]). Pilot testing was done with a small group of volunteers, who worked later as *facilitators* at different colleges. The experiments were conducted on the students during August-September 2010. Innovative experiments were first conducted on the students of Vijayanagar College, Hospet (See Table I). Students representing sample-1 were studying in third year, they had participated in the survey when they were in second year of B.Sc. Out of a total of 71 students, 35 were selected randomly to represent experimental group and the experiments were conducted on them in two consecutive days. On the second day they were asked to complete the posttest. The remaining 36 students, who represented the control group, were asked to respond only to the posttest and let go. Students representing sample-2 were studying in B.Sc. second year. They had not participated in the survey, as they were not exposed to undergraduate laboratory course, when survey was conducted in (August-September) 2009. Out of 82 students who volunteered to partake in the exercise, 40 were put in the experimental group and 42 in the control group. Later for analysis purpose, to have equivalent groups, these numbers were readjusted.

III. ANALYSIS AND RESULTS

In Soloman four group design, ***treatment*** and ***pretest*** are the two independent variables and the set of ***post test scores*** is the dependent variable. Variable *treatment* has two levels: **experimental** and **control** and the variable *pretest* has two levels: **Pretested** and **un-Pretested**.

A. Main effect

We have a total of two *main effects* in this study: one for *treatment* and the other for *pretest.* The mean marks obtained in the posttest by the four groups for the four possible conditions of this study are given in Table IV.

TABLE IV. Mean test score by Pretest and Treatment.

	Treatment		
	Experimental group	Control group	Average
Pretested	Group-1 Mean=14.78	Group-2 Mean =7.20	**10.99**
Un-Pretested	Group-3 Mean= 14.3	Group-4 Mean= 6.25	**10.28**
Average	**14.54**	**6.73**	

Students of experimental group have scored, on an average, 7.81(14.54−6.73) marks more than the students of control group, which indicates that there is a *main effect* of treatment. Similarly, un-Pretested students have scored 0.71(10.28−10.99) marks more than the pretested students. To determine whether the main effect of pretest and treatment is significant, we need to test whether these differences are greater than that we expect by chance.

B. Interaction effect

As mentioned earlier, an interaction effect exists when the effect of one independent variable on the dependent variable changes depending on the level of another independent variable (pretest). In the conducted exercise, we had pretest and treatment as two independent variables and the scores of students in the posttest as the only dependent variable.

To detect the significance of main effects and interaction effect we used ***SPSS 16.0*** software. We did three statistical tests at once: one for each of the two possible main effects and one for the possible interaction effect. Table V shows the summary of analysis of variance (ANOVA).

TABLE V. Tests of Between-Subjects Effects (ANOVA).

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Corrected Model	9920.702[a]	3	3306.901	699.347	.000
Intercept	72861.025	1	72861.025	15408.739	.000
Treatment	9829.590	1	9829.590	2078.774	**.000**
Pretest	82.143	1	82.143	17.372	**.000**
Treatment * Pretest	8.969	1	8.969	1.897	**.169**
Error	3026.273	640	4.729		
Total	85808.000	644			
Corrected Total	12946.975	643			

Since the significance level (p-value) corresponding to treatment*pretest is 0.169 which is more than the 0.05 (α-level at 95%), there is no interaction effect. The p-values corresponding to the treatment and pretest are zero. There is main effect between control group and experimental group and also between pretested and un-Pretested groups. *Prima-facie*, there is a pretest sensitivity, but from the F-ratio it is evident that *between group variance* is not substantially greater than the *within group variance*. Hence it can be concluded that the difference between the means is probably only a reflection of sampling error.

C. Levene's test

We did Levene's test to test if samples have equal variances. Equal variances across samples are called homogeneity of variance. While doing the ANOVA tests on the groups it is assumed that the variances are equal across groups.

TABLE VI. Levene's Test of Equality of Error Variances.

F	df1	df2	Sig.
36.121	3	640	0.000

From Table VI it is evident that critical value of *F* statistics (36.121>0.000) is greater than the significant value at α =95%, thus we accept the null hypothesis that variances are equal across the groups. Figs. 1 and 2 provide graphical representations of the mean scores of experimental and control group with and without pretest.

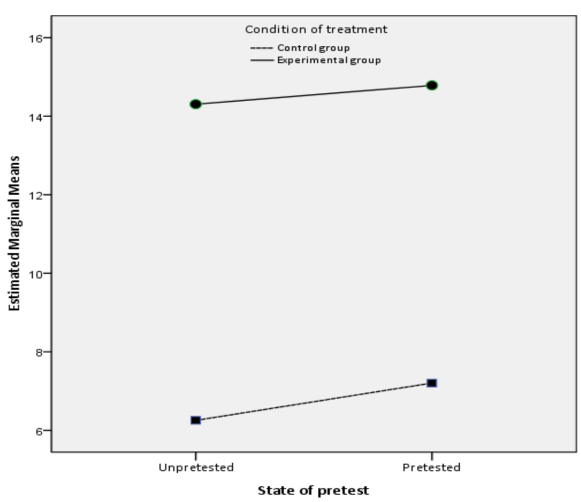

FIGURE 1. Estimated Marginal Means of Marks Scored.

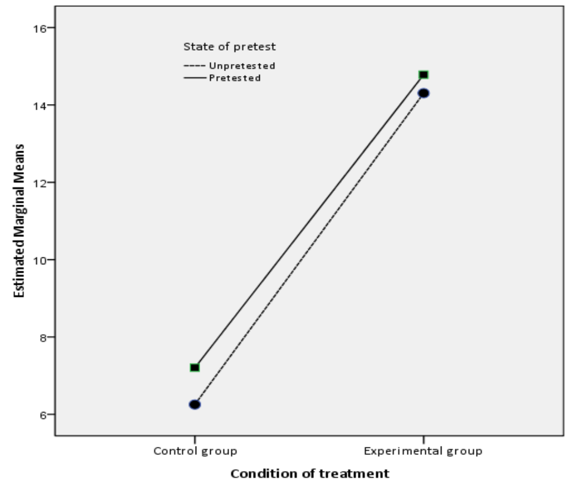

FIGURE 2. Estimated Marginal Means of Marks Scored.

The parallel lines indicate that there is no interaction effect, In other words, the treatment or the posttest scores are unaffected by the pretest. Solid line is above the dotted line which shows that there is main effect of the treatment: the experimental group has performed significantly better than the control group.

IV. CONCLUSION

The strength of the relationship within related aspects of student performance increased from pretest to posttest, suggesting that instruction improved the connection between different measures of the same aspect of student performance. From the analysis of the posttests we found a strong evidence suggesting improvement in the conceptual understanding.

REFERENCES

[1] Khoon, K. A. and Othman, M., *Some thoughts on the introductory course in physics,* College Student Journal **38**, 503(2004).

[2] Boud, D. J., *The laboratory aims questionnaire a new method for course improvement?,* Higher Education **2**, 81–94 (1973).

[3] Lazarowitz, R. and Tamir, P., *Research on using laboratory instruction in science,* In D. L. Gabel (Ed.) Handbook of Research on Science Teaching and Learning, (Maxwell Macmillan International, New York, 1994).

[4] Millar, R. and Driver, R., *Beyond processes*, Studies in Higher Education **14**, 33–62 (1987).

[5] AAPT American Association of Physics Teachers, G*oals of the introductory physics laboratory*, The Physics Teacher **35**, 546–548 (1997).

[6] Reif, F. and St. John, M., *Teaching physicists' thinking skills in the laboratories,* American Journal of Physics **47**, 950–957 (1979).

[7] Agrest, M. M., *Physics Labs with Flavor*, The Physics Teacher **47**, 297–301 (2009).

[8] Pattar, U., Raybaghkar, V. H. and Garg, S., *Assessing the Effectiveness of Learning-Teaching Physics Through Traditional Laboratory Experiments,* Lat. Am. J. Phys. Educ. **5**, 517-523 (2011).

[9] Best, J. W. and Kahn, J. V., *Research in Education,* 10th Ed. (Pearson Education, India, 2008), pp. 165-192.

[10] Kothari, C. R., *Research Methodology Methods & Techniques,* 2nd Ed. (New Age International (P) Limited, 2006) 31-69.

[11] Clark, A. M., *The qualitative-quantitative debate: Moving from positivism and confrontation to post-positivism and reconciliation,* Journal of Advanced Nursing **27**, 1242–1249 (1998).

[12] Huck, S. & Sandler, H. M., *A note on the Solomon 4-group design: Appropriate statistical analyses*, Journal of Experimental Education **42**, 54-55 (1973).

[13] Helmstadter, G. C., *Research concepts in human behavior: Education, psychology, sociology*, (Appleton-Century-Crofts, New York, 1970), p. 110.

[14] Campbell, D., & Stanley, J. (1963). *Experimental and quasi-experimental designs for research.* Chicago: Rand McNally.

[15] Braver, M. C. W. & Braver, S. L., *Statistical treatment of the Solomon Four-group design: A meta-analytic approach*, Psychological Bulletin **104**, 150-154 (1988).

[16] Best, J. W. and Kahn, J. V., *Research in Education,* 10th Ed. (Pearson Education, India, 2008), pp. 423-424.