A PRELIMINARY EVALUATION OF UNDERGRADUATE PHYSICS LABORATORY INSTRUCTION OFFERED AT IGNOU

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ABSTRACT

In the undergraduate physics laboratory, a student is expected to make precise measurements, hone investigative skills and discover the interplay between experimentation and fundamental principles underlying physical phenomena. But in India, the mainstream conventional UG physics laboratory instruction has all along been cookbook in nature. In such a scenario, incorporating innovative and meaningful laboratory experience in Open and Distance Education programmes becomes a formidable challenge. Recently we evaluated the physics laboratory courses, which are integral to the B.Sc (Physics) programme of IGNOU offered at a distance, for their quality, relevance and effectiveness. Our findings reveal that these courses are being received well particularly by those students who are pursuing the B.Sc (Major) in Physics. The success rates improve as learners evolve in the system and their satisfaction levels are high. However, factor analysis of learners' perceptions brings forth six factors guided approach, student-centered learning and assessment, emphasis on self-learning, use of multimedia and innovative non-conventional teaching strategies, increased student participation and emphasis on problem solving as key determinants for further improving the quality of learning in physics laboratory.

Keywords: ANOVA test, open and distance education, self-learning materials, programme evaluation, factor analysis, Kaiser criterion

Physics is an experimental science and now embodies a vast pool of knowledge accumulated through continuous testing of theories and their refinement, verification of theoretical predictions and vice versa. That is why laboratory work has been an integral component of the Physics curriculum at all levels. Informed by systematic researches in physics education in the last few decades, the instructional objectives in physics laboratories have been evolving and there has been a shift towards creating new learning environments to promote meaningful engagement in the learning of physics (Hake, 2008; Van Heuvelen & Et-kina, 2006; Sokoloff & Thornton, 2004; Laws, 2001; Jossem, 2000; McDermott & Redish, 1999). Laboratories in such models are primarily based on "discovery" learning; that is, the instruction is planned so that students observe phenomena, design experimental activities, control variables and in the process arrive at an understanding of the fundamental principles underlying physical phenomena.

In India, such innovations in the teaching-learning of physics have somehow not impacted Physics teaching much, particularly at the undergraduate level. In fact, Physics laboratory instruction in India has all along been "cookbook" in nature. As such, laboratory work consists of performing pre-set repetitive experiments, that is, students go through a prescribed series of steps in order to verify certain laws or concepts learnt in theory classes or from standard text books. It definitely does not promote scientific investigative skills or an understanding of the subtle interplay between observation, experimentation and the construction of physics theories. As a result, most students tend to view physics as merely an abstract collection of laws, theories, mathematical equations and textbook problems rather than as a way of understanding and modelling physical phenomena.

This situation prevails despite some innovations introduced at the UG level by individual teachers / researchers and a few institutions in India. This includes the use of home kits to perform simple experiments (Sane, 1999) and micro-processor based laboratory with appropriately synergised software (Jolly, 1992). However, these have not led to any major reforms in teaching-learning in the conventional UG Physics laboratories in the country. This is in spite of repeated policy pronouncements to the effect that “science education programmes will be designed to enable the learner to acquire problem-solving and decision making skills and to discover the relationship of science with health, agriculture, industry and other aspects of daily life. Every effort will be made to extend science education to the vast numbers that have remained outside the pale of formal education”. (Education Commission Report, 1964-66, the National Policy on Education, 1986 and MHRD, 1992).

In such a scenario, imparting meaningful laboratory experience in distance education programmes is considered a formidable challenge in India. That is why in spite of the acceptance of open education as a powerful alternative, opportunities to study science at a distance have remained rather limited. Purists in the Indian academia still believe that for a proper understanding of science subjects, face-to-face student-teacher contact is a must.

When Indira Gandhi National Open University decided to offer the B.Sc. programme at a distance in 1991, the foremost challenge that confronted the programme designers was to incorporate innovative and meaningful laboratory experience in the curriculum. Recently, while evaluating the quality, relevance, effectiveness and acceptability of the B.Sc. (Physics) programme of Indira Gandhi National Open University offered at a distance, an appraisal of the Physics laboratory courses was also carried out. The researchers ascertained the original goals envisaged for teaching-learning in the UG physics laboratory courses in IGNOU, the considerations underlying course design, the constraints of implementation and the complexity of the environment. Student enrolment, success rates, feedback from learners and the academics associated with the delivery (including counselling) was analysed using a variety of statistical techniques.

The findings suggested that it would also be desirable to study learners’ perception of what Physics teaching-learning should be like in an undergraduate laboratory. Factor analysis – a multivariate statistical technique – was used to analyse preferences of learners in order to make teaching–learning more meaningful and enjoyable in the Physics laboratory. This technique serves to reduce co-relational data involving multiple variables (even up to 100 or more) to a few underlying factors. It helped us to disentangle complex inter-relationships into six major and distinct regularities/patterns. In this paper we report the findings emerging from this study of undergraduate laboratory physics instruction in IGNOU.

METHODS

The research methods adopted to carry out the present study were

- Perusal of Institutional Records, Documents and Analysis of Databases, and
- Survey Method.

Records, Document and Database Analysis: Institutional information on the philosophy and guiding principles and practices for design, development and offer of the B. Sc. (Physics) programme and data on aspects such as learner enrolment, learner characteristics (employment status, social status, gender, etc.) was sourced from the University documents and records.

Survey Method: Questionnaires, interviews, observation, focus group discussion were used to probe deeper the variables and trends emerging from the analysis of institutional records and personal interactions of the researchers with students, IGNOU Faculty members and academic counsellors involved in laboratory instruction.

Eight research tools mostly in the form of structured, semi-structured and unstructured (open-ended) questionnaires were conceived, designed and administered in the main Programme Evaluation research study to factor in the experiences of all stakeholders as well as the institutional data. Questions about laboratory instruction were included in the questionnaire related to student feedback. The relevant portion of the questionnaire is given in Appendix 1. Another questionnaire about learner preferences for teaching learning containing 18 questions (variables) was administered on a subset of the general sample. The questionnaire is given in Appendix 2. A six point rating scale was used. The contents of the questionnaires were validated by the Faculty members of STRIDE (Staff Training and Research Institute in Distance Education), IGNOU, involved in research of Programme Evaluation and a few Faculty members of the School of Sciences and the School of Education.

Within the general framework of various categories of evaluation methodology, the following specific techniques were included in this research:

- Feedback through questionnaires and interviews using multiple channels of communication (face-to-face, post, phone, e-mail) on aspects such as course content, learning experiences, study environment, and study outcomes.
- Direct observation of students in the laboratory courses at select study centres.

Selection of Sample and Methods of Survey

The data on student enrolment available in the institutional records at the Student Registration and Evaluation Division (SR&ED) of IGNOU for the period December 1997 – December 2005 revealed that the average number of students enrolled in Physics electives in a year was 1899. The sample sizes required for proper statistical inference with this population at two different

(95%, 99%) confidence levels and 5% confidence interval are 320 and 493, respectively. In this study, responses were received from 509 students. This sample size meets the requirement of 99% confidence level and 5% confidence interval.

Methods of Survey

- Selecting a truly random sample;
- Personal visits to 16 Study Centres in different parts of the country;
- Administration of questionnaires in the laboratory classes;
- Sending questionnaires by post to IGNOU Study Centres; and
- Administration of questionnaires during personal interviews and through e-mail.

Sample of the Study

Learner population studying the undergraduate Physics programme is distributed over all Study Centres activated by IGNOU for its B.Sc. programme. These are spread across the length and breadth of the country from Kargil to Campbell Bay and Kutch to Itanagar and numbered 156 (as per the Programme Guide for the B.Sc programme for the year 2004-2005) at the time of data collection. The prime consideration of the researchers was to select a sample representative of the system and to ensure that the selected centres represent an all India picture. The randomly chosen sample of 509 learners from 32 study centres (out of 156 activated by the University) comprises learners from all over India (Table 1).

Table 1. Region-wise Distribution of Sampled Study Centres and Learners

Region	Region Number of sampled study centres	Number of sampled students	Percentage (%)
Northern region	15	337	66.21
Eastern region	7	92	18.07
Southern region	7	40	7.86
Western region	3	40	7.86
Total	32	509	100

Table 1 reveals that 337 (66.2%) respondents were from the North, 40 (7.85%) from the South, 92 (18.07%) from the East and 40 (7.85%) from the West. These students were attached to 32 Study Centres from all over India and comprised fifteen centres from the Northern region, seven centres from the Southern region, seven centres from the Eastern region and three centres from the Western region. Of these 32 study centres, 16 study centres were personally visited by one of the researchers to administer various Research Tools on learners and counsellors.

A survey of the enrolment data of learners for the years under study (Mishra, 2008) revealed that 45-50% learners enrolled in B.Sc from the Northern region, 25-30% from the Eastern region, 15-20% from the Southern region and 5-10% from the Western region. Therefore, the region-wise distribution of the sampled learners may be regarded as fairly representative of the general enrolment trends.

A sub-set of 199 learners, who intended to pursue B.Sc (Major) in Physics, out of the total sample of 509 was identified and further interaction with them was undertaken through telephonic and face-to-face interviews. A questionnaire containing 18 questions (variables) was also administered on 32 students from this subset of 199 learners to know their opinion on further improvement in laboratory instruction. The questionnaire yielded a data set in a 32 × 18 matrix, which was analysed using Factor Analysis.

In addition, feedback of 54 academic counsellors and four IGNOU Physics Faculty members of the School of Sciences were taken through structured and open-ended questionnaires and face-to-face interviews. Institutional data was obtained from Student Registration & Evaluation Division, Student Task Force and Physics Faculty of School of Sciences.

Scheme of Data Analysis

Given the size of the population for the study, a sample size of 509 is statistically adequate at 99% confidence level and 5% confidence interval. Data was analysed in MS Access and in MS Excel. Qualitative and Quantitative data was compiled, grouped and analysed in simple and narrative style. The structured data has been presented through computation of percentages. The t-tests and ANOVA tests were applied to compare success rates obtained from institutional sources for different lab courses. Factor analysis was used to analyse learner suggestions for improving the lab courses. The SPSS software package was used to carry out statistical analysis of the responses. The unstructured data was compiled, ranked and ordered to assess popular responses. Before reporting the findings emerging from the analysis of data obtained in this study, we discuss the context in which the B.Sc programme in Physics was launched.

CONTEXT: BACHELORS PHYSICS PROGRAMME AT IGNOU

A perusal of the institutional documents reveals that while drawing up the curriculum for the B.Sc. (Physics) programme, the designers at IGNOU were influenced by concerns of parity with conventional universities so that students were regarded to be on par with their conventional peers by higher educational institutions, society and employers. Moreover, special care had to be taken to overcome the misconception of the academia as well as prospective employers that: i) science education through distance mode was a less effective mode of instruction compared to science education on campus, ii) the products of the system were given inferior training, and iii) it was a refuge for failures of the formal system (Vijayshri et al., 1998). Accordingly, the structure finalised for the IGNOU B. Sc. Programme in Physics resembled that of any standard conventional University (Table 2), though the presentation of the courses and evaluation of learners were significantly different. It may be noted from Table 2 that three laboratory courses worth 12 credits (25% of total work load) were offered to provide practical training in UG physics.

We now elaborate the considerations underlying the design of the laboratory component as gleaned from institutional records and responses of IGNOU Physics Faculty.

Table 2. B.Sc. Physics Elective Courses Offered by IGNOU

Level$	Course	Credits
1st	Elementary Mechanics	2
	Oscillations and Waves	2
	Physics Laboratory-I	4
2nd	Mathematical Methods in Physics-I	2
	Mathematical Methods in Physics-II	2
	Thermodynamics and Statistical Mechanics	4
	Electric and Magnetic Phenomena	4
	Physics Laboratory-II	4
3rd	Optics	4
	Electrical Circuits and Electronics	4
	Modern Physics	4
	Physics Laboratory-III	4
	Physics of Solids	4
	Mathematical Methods in Physics-III	4
	Astronomy and Astrophysics	4
	Communication Physics	4

$ These levels are notional indicating only the difficulty level of the courses, as also the order in which IGNOU offers them. Students have the flexibility of opting for a minimum of 8 credits and a maximum of 48 credits (out of 56 credits available in Physics) spread over a period of 3 to 6 years; one credit is equivalent to 30 hours of student work. A student taking 48 credits in Physics is awarded a B. Sc. (Major) in Physics.

PHYSICS LABORATORY COMPONENT

Leading experimental physicists with considerable research and teaching experience were drawn from all over the country and associated with IGNOU Physics Faculty to design and develop the laboratory component of its UG Physics curriculum. While designing the experimental component of B.Sc. (Physics), they analysed the problems of conventional laboratory courses, which persist to this day and have been summarized succinctly by Desai and Chakrabarti (2007), and Chakrabarti (2007, 2008) as follows:

- non-availability of competent teachers with aptitude for experimental work and inadequately equipped laboratories;
- inappropriate emphasis on acquisition of investigative skills;
- non-inclusion of experimental component in entrance tests for admission in professional courses after the + 2 level of schooling and Masters Programme after Bachelor of Science degree;
- unimaginative / stereotype list of experiments with little scope for innovations;
- lack of institutional policy for periodic revision of syllabi to upgrade the contents and make these more relevant and contemporary; and
- lack of correlation between the grades awarded and skills acquired.

Chakrabarti (2008) argues that without exception, the emphasis of teachers and learners is on getting the ‘right’ result rather than the process (of taking unbiased observations) for developing experimental skills progressively. Moreover, the same process is repeated year after year and learners gather an impression (most probably from their seniors) that mere completion of experiments is enough to get good marks. In fact, lack of experimental culture has led to deterioration in the quality, content and effectiveness of laboratory instruction in the teaching-learning of Physics at school as well as college level. Learners hardly learn any skill to design a new experiment.

Given the resource crunch faced by higher education institutions in India, suggestions have been forthcoming for using low cost equipment to design simple, innovative, investigative (open-ended) experiments (Joshi, 2008). However, till such time that these ideas are accepted by the wider community of Physics teachers, legislated by the institutions, and supported through university- industry interface, there may not be any worthwhile outcome.

LABORATORY COURSES: DESIGN AND IMPLEMENTATION SCHEME

It is heartening to note from institutional records that at IGNOU, these considerations were uppermost in the minds of the Experts as they designed the UG laboratory component in Physics. They also benefited from the experience of the Open University, UK, which had redesigned laboratory work and used television (later video and computer- mediated simulation), home kits and residential schools as integrated components to provide experimental experience. This value addition had proved beneficial in two ways: it had helped the learners in appreciating basic concepts better and the Open University had gained respect on par with that of conventional institutions as well as the employers.

The course designers were unanimous in their view that laboratory experience should provide students the opportunity to be trained in the method of acquiring knowledge in Physics, i.e., the opportunity for observing phenomena, analyzing data, and developing qualitative and quantitative models to explain observations and thus relate observable phenomena to scientific theories. Students should also acquire an understanding that experimental evidence forms the basis of the laws of Physics and the knowledge derived from them. Accordingly, three laboratory courses were designed in Physics with the goals of

- exposing learners to the experimental processes in scientific investigations, including some experience in designing and conducting experiments for problem solving in physics;
- helping learners develop a range of basic experimental skills such as handling equipment, conducting experiments, taking observations and measurements, analysing data, writing a report along with error analysis; and
- helping students learn the basic concepts and develop collaborative learning skills.

The laboratory courses were designed and instructional materials were developed ostensibly to meet these objectives. The course designers had also recognised that the curricular transaction of experimental component prevalent in the conventional UG laboratories led to inefficient utilisation of time. Thus, the element of repetition in the traditional laboratory instruction was eliminated and so were the experiments which neither trained students in the craft of an experimentalist nor developed fascination for the subject, to make way for new ideas and experiments. With a view to promote active learning and nurture creativity, open-ended and table-top experiments were included in the lab courses to provide for an essential core of practical experience.

The total laboratory experience worth 12 credits was designed as an intensive hands-on training programme in the face-to-face mode. Learners were required to spend a total of 12 × 30 = 360 hours on practical work. It involved doing practical work on 14 days per lab course, i.e., a total of 14 × 3 = 42 days in intense sessions of 4 × 2 = 8 hours each day in a well-equipped UG Physics laboratory. Students were expected to write reports, watch video programmes and discuss their work with their peers. The duration of laboratory work was thus almost at par with the time spent by a learner in laboratory training in the conventional system.

Institutions (colleges and universities) where the practical work was to be carried out belonged to the conventional system of education, and were selected as B. Sc. Study centres of IGNOU. Great care was taken to select reputed institutions keeping in view the quality of their infrastructure as well as the qualifications and experience of their Faculty, who would work as the academic counsellors teaching the laboratory courses. One academic counsellor was assigned to 14 students attending a lab course. A policy decision was also taken to augment the conventional laboratories as per the requirements of the newly designed courses.

To provide an interacting and stimulating experience, the curriculum designers laid greater emphasis on day-to-day work in the lab and accorded it 70% weightage in the final grade with the term-end examination held on the last day being given only 30% weightage. Thus, it was envisioned that learners would be assessed continuously for the practical skills and training they acquired in the laboratory. Orientation programmes were held initially for the academic counsellors on how to conduct the lab work and guidelines were sent to them on how to assess the students for the continuous component. Students were required to successfully clear both components with a minimum pass percentage of 36% in each component to be able to complete the course.

EXPERIENCES OF IMPLEMENTING LAB COURSES: FACULTY PERSPECTIVE

At the time of this study, the laboratory courses had been running for about 15 years. The researchers' interviews with the academic counsellors and Physics Faculty members at IGNOU and a perusal of the relevant institutional documents revealed that the efforts for introducing new experiments in the first year lab course did not yield 100% satisfactory results initially due to

- non-availability of required equipment in the conventional college laboratories, where practical classes were held for IGNOU learners; and
- inability of the University to supplement these labs for want of the interest of manufacturers in low quantities.

Learning from the experience of the initial years, the Physics Faculty at IGNOU pushed for development of video programmes for two experiments of the first year laboratory and for fabrication of equipment for four experiments of the third level Physics laboratory course. After long search and detailed scrutiny, an erstwhile Faculty member of IIT, Madras (now renamed as Chennai) was persuaded to develop the prototypes. Subsequently, a group of young entrepreneurs fabricated the equipment under the supervision of the then Regional Director, Chennai Regional Centre, who was a permanent IGNOU functionary and one of the course coordinators. These sets were sent to different study centres in 1994-1995. Similarly, the equipment for new experiments in the first level lab course was got fabricated in Kolkata and provided to majority of the study centres activated for the programme in 2004.

However, due to rapid increase in the number of study centres, change of guard at the policy decision making level, and above all cumbersome University procedures, the enthusiasm for follow-up was dampened and all innovations got bogged down. There was virtually no systemic feedback mechanism to inform the IGNOU Faculty of the way the courses were being conducted. Personal initiatives led them to visit local study centres (at Delhi) while the laboratory courses were being conducted and also act as External Examiners to gauge the extent to which instructional goals and learning outcomes matched in these courses and how effectively the counsellors were engaging the students. The academic counsellors with whom the faculty members interacted in these visits pointed out constraints such as lack of preparedness on the part of students, lack of motivation in students who were not pursuing a B. Sc. (Major) in Physics, too much of flexibility in the system that made the students relaxed as far as completing the course was concerned, lack of prompt financial support to study centres, etc. However, in their opinion, the contents and design of the lab courses were of a high standard.

From these experiences it emerged that the ground reality needed to be probed all over the country in a systematic manner. It also seemed that far greater institutional initiative and commitment as well as systemic intervention were required to achieve instructional goals envisaged for teaching-learning in the Physics laboratory. As things stand today, IGNOU Physics laboratory courses are conducted in its Study Centres (located in conventional institutions) in whichever way the academic counsellors are at ease with and the Physics Faculty has very limited feedback on the conduct of the courses. Hence this investigation on lab courses was undertaken by the researchers as a significant part of the B. Sc. (Physics) programme evaluation.

LEARNER ENROLMENTS AND SUCCESS RATES: ANALYSIS OF INSTITUTIONAL DATA

There has been a substantial growth in student enrolment in the B.Sc. programme in general, and in the Physics courses, in particular (Tables 3a and b). It may be noted that starting with an enrolment of 1210 students in the B.Sc. programme from all over the country, the number of students reached a high of 9973 in 2003 and the total number of students today runs into several tens of thousands.

It may be noted from Tables 3a and b that for the period 2000 to 2006,

- learner enrolment in the first level lab course PHE-3L varies from a high of 45% in 2000 to a low of 16% in 2003; the average enrolment being 30%.
- The average enrolment decreases as the level of course increases with 27% learners enrolling in the second level physics lab course PHE-8L and 21% in the third level course PHE-12L.

This behaviour suggests that the 2nd and 3rd level laboratory courses are usually opted for by those learners who are interested in majoring or pursuing master's degree / career in Physics.

Table 3. Learner Enrolment in Different Levels

a. B.Sc. Programme of IGNOU

Year of programme Year of enrolment	I	II	III
1991	1210		
1992	1465	538	
1993	1917	670	
1994	2100	1022	382
1995	2358	1046	736
1996	2045	1209	670
1997	2727	1372	906
1998	2761	1525	880
1999	2391	1322	1108
2000	2372	1207	968
2001	3958	2007	899
2002	4396	2215	1349
2003	9973	2701	1532
2004	6026	2271	1852
2005	6446	3138	1511
2006	6244	3507	2248
2007	5089	3185	2248
Total	63478	28935	17289

b. Enrolment in Physics Courses in the Period 2000-2006

Year Course Code	2000	2001	2002	2003	2004	2005	2006	Total	Average enrolment
PHE01	1253	1449	1364	1500	2224	2176	1904	11870	1696
PHE02	1253	1449	1364	1500	2224	2176	1904	11870	1696
PHE03L	1072	1460	1469	1651	2292	2054	1619	11617	1660
PHE04	263	605	653	1587	881	903	730	5622	803
PHE05	263	605	653	1587	881	903	730	5622	803
PHE06	315	792	788	2100	1466	1424	998	7883	1126
PHE07	362	495	515	1302	819	746	NA	4239	707
PHE08L	384	576	559	1520	910	722	NA	4671	779
PHE09	211	349	347	972	584	566	NA	3029	505
PHE10	270	389	404	993	632	569	NA	3257	543
PHE11	171	213	214	538	296	NA	NA	1432	286
PHE12L	241	325	330	789	456	NA	NA	2141	428
PHE13	78	183	184	429	219	NA	NA	1093	219
PHE14	91	164	172	381	147	NA	NA	955	191
PHE15		1	3	118	231	NA	NA	353	88
PHE16			3	108	207	NA	NA	318	106

Source: Dr. Srikant Mohapatra (Personal Communication) ; NA: Not Available

ANALYSIS OF SUCCESS RATES

Khare et al. (2003; 2004) had analysed institutional data for success rates for four elective courses offered in the B.Sc. programme of IGNOU using data mining technique and reported that students who appeared in final examination between 1992 and 2002 managed to complete laboratory courses with greater success than theory courses. These findings are corroborated in the current study for success rates in the three laboratory courses in Physics for learners enrolled in years 2000-2005 (Table 4).

The average success rates in the laboratory courses (ranging from 65% to 98%) are far better than the average success rates in B. Sc. physics theory courses, which range from 28% to 53% (Mishra, 2008). (This is also in conformity with the national trend in the conventional system.) These defy the initial scepticism of conventional peers and fears of practitioners of open learning. Furthermore, it is satisfying to note that these are significantly higher than the overall success rate of learners in B.Sc. Only 3,000 (17%) learners out of a total of 17289 learners enrolled in the third and final year of the programme till 2007 have managed to successfully complete all requirements for the award of degree in the last convocation held in 2008. This implies that only about 4.7% of all learners who entered in the programme since its inception in 1991 and paid fee in the first year have succeeded so far. Of these, only 346 learners have been awarded B.Sc. (Major) in Physics so far. These are the students who have taken all lab courses on offer in Physics (Mishra, 2008).

Table 4. Success Rates in Physics Laboratory Courses in the Period 2000-2005

Course Year	PHE03L	PHE08L	PHE12L
2000			
2001	53	64	
2002	60	59	100
2003	47	66	94.2
2004	69	72	98.3
2005	98.6	98	98.4
Mean	65.5	71.8	97.7
Std dev	20.23	15.37	2.47
tvalue	2.776	2.776	3.182

The tvalues of each of the respective single sample are also given in Table 4. We note that the tvalue for df = 4 is 2.7765 for 95% confidence interval. Since the calculated tvalues for the samples of both PHE03(L) and PHE08(L) are 2.776, the null hypothesis that there is no difference between the sample mean and the population mean cannot be rejected. Similarly, for PHE12(L), the tvalue for df = 3 for 95% confidence interval is 3.1824 from the ttable. Since the calculated tvalue for PHE12(L) is 3.182, the null hypothesis that there is no difference between the sample mean and the population mean cannot be rejected. However, when the three groups are compared simultaneously, we get a different result.

There is statistically significant difference in mean success rates in the three Physics laboratory courses as discovered from the oneway ANOVA test. For analysis of variance, we must know the number of observations, mean and standard deviation for each group. These are given in Table 4. The pvalues and Fvalues (which is the ratio of variance between groups and variance within groups) have been calculated for the three lab courses, PHE03 (L), PHE08 (L) and PHE12 (L). The results are tabulated in Table 5.

Table 5. ANOVA Test for Physics Lab Courses

Course Variable	PHE03(L)	PHE08(L)	PHE12(L)
Mean pass percentage	65.5	71.8	97.7
σ	20.23	15.37	2.47
N	5	5	4

ANOVA Table

	Source of Variation	Sum of squares	dF
i)	Source of Variation	Sum of squares	dF
ii)	Between groups	2510.3750	2
	Within groups	2600.2619	11
	Total	5110.6369	13

Variance	F	p
i) 1255.19	5.31	0.02
ii) 236.39	Statistically significant	

$$F_c = \frac{\text{variance betweengroups}}{\text{variancewithingroups}} = (1255.19) / (236.39) = 5.31$$

Ft = 3.98

That is, Fc > F_t, which means that the difference between mean success rates is statistically significant.

This result did not seem very surprising to the researchers. It did emerge from the personal interviews with learners and counsellors, focus group discussions with the learners and direct observations of the conduct of labs that learners enrolled in the 2nd and 3rd level lab course possessed higher motivation levels. They were keen learners and also desired to do well in their studies. Moreover, learners enrolled in the 3rd level lab course were pursuing B. Sc. (Major) in Physics and seemed to be well versed with the subject as well as the system.

Learner and Counsellor Feedback on the Lab Courses

Learner feedback on the organisation, interactivity and utility of the Physics laboratory courses is given in Table 6. As may be noted, about 90% distance learners opine that lab sessions are well planned and structured, lively and stimulating, help them to learn a lot and they look upon practical sessions as an enjoyable experience, which also relate theory to practice. About 82% of the sampled learners reported that the instructors took keen interest in teaching in the laboratory courses and clarified their doubts.

It was a pleasant experience to discover in personal interactions with the learners that they preferred to earn maximum possible credits in practical / labbased courses. The basic considerations seem to be full time facetoface guidance provided in Physics laboratory courses, intense training sessions, high success rates and better grades.

Interviews with the academic counsellors of the laboratory courses revealed that they were very satisfied with the design of the laboratory courses and many felt that the motivated students were able to learn a lot more in much less time in these intense laboratory sessions than in the conventional system. However, suggestions were given to include Newton's rings experiment, Fresnel's Biprism, HeNe laser to measure diameter of a wire and Lee's disc method in the 2nd level laboratory course PHE08(L) to improve its coverage.

Given these findings, the researchers endeavoured to investigate learners' perceptions on how to improve the quality of teachinglearning in these courses, which could also help evolve the best strategies for teaching undergraduate Physics through laboratory in ODL mode. To this end, 32 students were administered a questionnaire (see Appendix 2) containing 18 questions (variables), as mentioned earlier. A six point scale was used.

Table 6. Learner Responses on Practical Sessions

Practical sessions	Unsure	Disagreed	Agreed	Strongly agreed
Instructor takes keen interestΘ	45 (9.9%)	35 (7.7%)	260 (56.8%)	117 (25.6%)
Cover key areas and ideas*	25 (5.6%)	12 (2.7%)	296 (66.2%)	114 (25.5%)
Instructor clarifies doubts£	35 (7.8%)	48 (10.7%)	270 (60.1%)	96 (21.4%)
Relate theory to practice#	21 (4.7%)	8 (1.8%)	307 (68.4%)	113 (25.1%)
Well planned and structured$	40 (9.1%)	20 (4.6%)	269 (61.1%)	111 (25.2%)
Lively and stimulating@	29 (6.6%)	13 (3.0%)	284 (64.8%)	112 (25.6%)
Learners look forward to practicals+	18 (3.9%)	9 (2.0%)	134 (29.2%)	298 (64.9%)
Learners enjoyed lab sessionsђ	11 (2.4%)	12 (2.6%)	112 (24.5%)	323 (70.5%)
Learners learnt a lot in lab sessionsβ	15 (3.2%)	4 (0.9%)	122 (26.4%)	322 (69.5%)

No response out of a total sample of 509: 52[Θ]; 62*; 60[£]; 60[#]; 69[$]; 71[@]; 50[+]; 51[ђ]; 46[β]

We now report the results of the factor analysis carried out on the resultant data set obtained in the form of a 32 × 18 matrix.

Factor Analysis of Data

The input data matrix is given in Table 7.

Table 7. Factor Analysis: Input Data Matrix

Var Student	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	5	0	5	5	4	5	5	3	5	5	4	5	5	4	5	5	5	3
2	5	5	3	5	5	5	5	1	4	5	5	5	0	0	5	4	5	5
3	5	1	4	5	0	4	5	3	5	4	5	5	5	4	4	5	4	5
4	5	3	4	4	4	5	5	4	4	4	5	5	5	5	3	4	4	5
5	5	1	3	4	2	4	4	3	5	5	4	5	4	2	3	4	4	5
6	5	5	5	5	5	5	4	5	5	5	5	5	5	5	5	5	0	5
7	5	0	4	5	0	5	3	4	5	5	5	5	5	3	5	5	4	5
8	5	4	5	5	5	5	5	4	5	5	1	5	5	5	0	5	4	0
9	5	4	5	5	5	5	5	4	5	5	1	5	5	5	0	5	4	0
10	5	1	1	1	1	2	4	2	0	3	0	0	5	5	5	5	5	5
11	5	4	3	5	5	4	5	4	5	3	5	3	5	4	4	4	4	4
12	5	3	2	4	3	4	4	4	5	5	4	3	4	5	5	5	3	4
13	0	1	2	3	4	5	5	4	3	2	1	0	5	4	2	3	3	1
14	5	4	3	2	1	0	5	4	3	2	1	1	5	4	3	2	1	0
15	5	4	3	5	4	5	5	3	2	3	4	5	5	4	5	5	4	5
16	4	5	5	3	3	2	2	4	0	5	3	4	5	5	3	3	5	5
17	3	0	0	5	5	5	0	5	5	5	3	5	5	5	0	5	0	0
18	5	5	0	3	5	3	4	4	4	2	4	5	5	5	5	4	4	5
19	3	2	4	3	3	4	3	2	3	1	4	3	3	4	4	4	3	4
20	4	3	3	3	4	2	3	4	3	4	4	3	4	4	3	4	3	4
21	5	5	5	5	5	5	5	4	5	5	5	5	5	4	4	5	5	5
22	4	2	5	2	3	5	5	4	0	4	2	4	1	0	3	4	4	3
23	5	4	5	5	4	4	3	3	5	4	3	4	5	5	3	5	4	4
24	4	0	5	2	5	5	3	2	5	4	1	0	0	3	4	5	1	2
25	3	5	0	1	4	3	2	3	5	1	2	3	5	2	0	4	5	5
26	3	5	0	1	4	3	2	3	5	1	2	3	3	3	4	1	2	5
27	5	4	5	4	4	2	4	4	4	5	4	4	4	4	2	4	4	3
28	5	5	4	5	5	5	5	4	5	3	5	5	5	5	5	5	5	5
29	3	2	4	1	0	3	2	3	1	3	2	5	5	0	2	5	5	5
30	5	2	4	1	5	2	4	2	0	2	5	5	5	5	5	5	5	5
31	5	4	3	2	4	5	5	4	2	4	4	3	5	2	2	4	4	0
32	5	0	4	5	0	5	5	3	4	5	5	5	5	3	5	5	4	5

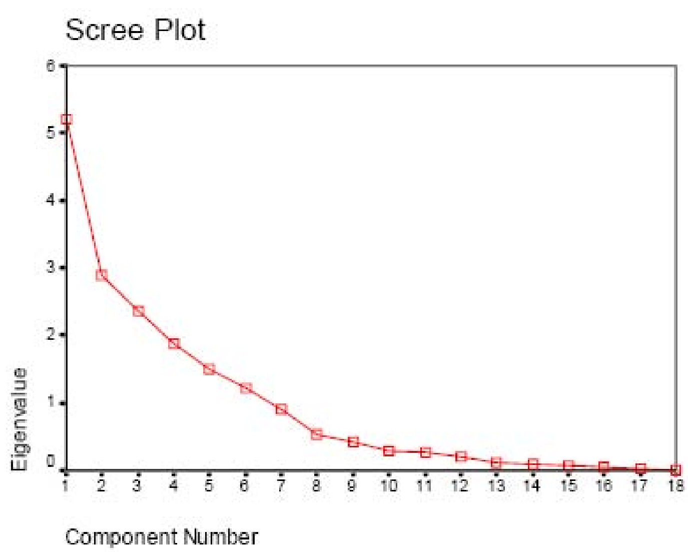
The Kaiser criterion and Cattel's scree plot have been used to extract the appropriate number of factors for final interpretation. The eigenvalues of the correlation matrix constructed from the initial data matrix are given in Table 8.

Applying the Kaiser criterion (eigenvalue greater than one), we take the number of factors extracted for our analysis to be 6. We observe from the cumulative % column of Table 8 that the six factors extracted together account for 83.6% of the total variance (information contained in the original 18 variables). Thus we are able to economize on the number of variables (as we have reduced the original 18 factors to 6 factors), while losing only about 16.4% of the information contained.

Table 8. Eigenvalues of the Correlation Matrix

Factor/component	Eigenvalues	% of Variance	Cumulative %
1	5.197	28.874	28.874
2	2.898	16.101	44.975
3	2.350	13.053	58.029
4	1.877	10.429	68.458
5	1.496	8.312	76.770
6	1.224	6.799	83.569
7	0.909	5.049	88.619
8	0.533	2.960	91.578
9	0.420	2.332	93.910
10	0.288	1.599	95.509
11	0.269	1.494	97.004
12	0.205	1.137	98.140
13	0.110	0.613	98.753
14	0.093	0.519	99.272
15	0.058	0.320	99.592
16	0.044	0.246	99.838
17	0.025	0.139	99.978
18	0.004	0.022	100.000

The scree plot for the data is shown in Fig.1. The curve begins to flatten between factors 6 and 7. So to be consistent with Kaiser Criterion, the number of factors extracted for the factor analysis of the data was taken as six.



Component number

Fig. 1: Scree plot of eigenvalues versus number of components

The unrotated component matrix giving the loadings of the eighteen variables on the six factors extracted using the principal components analysis is given in Table 9.

Table 9. Unrotated Component Matrix Showing Factor Loadings of 18 Variables on Six Factors

Variable	Component/factor					
	1	2	3	4	5	6
V1	0.673	0.124	0.079	0.076	0.327	0.491
V2	0.384	0.037	0.650	0.366	0.198	0.223
V3	0.572	0.115	0.450	0.408	0.287	0.063
V4	0.851	0.227	0.100	0.137	0.071	0.029
V5	0.485	0.197	0.240	0.365	0.360	0.329
V6	0.473	0.170	0.334	0.093	0.522	0.383
V7	0.659	0.371	0.116	0.112	0.388	0.358
V8	0.479	0.448	0.574	0.102	0.098	0.064
V9	0.274	0.441	0.087	0.338	0.576	0.440
V10	0.687	0.270	0.226	0.314	0.065	0.373
V11	0.492	0.647	0.083	0.354	0.168	0.046
V12	0.655	0.547	0.184	0.225	0.092	0.164
V13	0.449	0.184	0.770	0.138	0.140	0.265
V14	0.559	0.265	0.142	0.480	0.199	0.199
V15	0.027	.453	.454	.596	.334	.066
V16	0.619	0.240	0.414	0.456	0.100	0.083
V17	0.552	0.577	0.310	0.324	0.282	0.204
V18	0.014	0.853	0.108	0.286	0.258	0.129

The Varimax rotation with Kaiser Normalization has been applied to obtain the rotated matrix from the unrotated components matrix. The rotated matrix is given in Table 10.

Table 10. Rotated Matrix Showing Factor Loadings of Different Variables on Six Factors

Variable	Component/factor					
	1	2	3	4	5	6
V1	0.690	0.165	0.247	0.357	0.196	0.315
V2	0.168	0.455	0.308	0.058	0.086	0.673
V3	0.827	0.008	0.169	0.009	0.155	0.243
V4	0.512	0.161	0.462	0.109	0.430	0.336
V5	0.029	0.023	0.281	0.181	0.741	0.204
V6	0.201	0.111	0.029	0.105	0.852	0.006
V7	0.260	0.094	0.868	0.004	0.201	0.075
V8	0.071	0.223	0.672	0.301	0.073	0.426
V9	0.141	0.238	0.044	0.117	0.382	0.824
V10	0.848	0.049	0.174	0.151	0.121	0.222
V11	0.157	0.411	0.118	0.782	0.057	0.012
V12	0.426	0.770	0.055	0.228	0.019	0.135
V13	0.104	0.798	0.500	0.127	0.154	0.002
V14	0.172	0.135	0.650	0.331	0.330	0.155
V15	0.022	0.219	0.032	0.901	0.006	0.143
V16	0.683	0.348	0.117	0.079	0.412	0.243
V17	0.147	0.936	o.072	0.071	0.224	0.055
V18	0.129	0.377	0.503	0.691	0.034	0.113

From Table 10, it is noted that variables 10, 3, 1, 16 and 4 have loadings of 0.848, 0.827, 0.690, 0.683 and 0.512, respectively on factor 1. From the unrotated factor matrix (Table 9), variable 4 also has a high loading (0.851) on factor 1. Hence, we combine all these variables to constitute factor 1, which captures the essence of these 5 variables as follows:

Guided Approach to Teaching Physics, which also promotes Cooperative and Exploratory Learning

Variables 17, 13, 12 have loadings of 0.936, 0.798, 0.770, respectively, on factor 2 in the rotated matrix. Hence, we club all these variables into a single factor:

Student Centred Learning and Assessment

Factor 3 is a combination of variables 7, 8 and 14 with loadings of 0.868, 0.678 and 0.65, respectively, in the rotated matrix. It can be termed as

Emphasis on Self learning through Accessibility of SLMs (Self learning materials) and Lab Demonstrations

Factor 4 is a combination of variables 15, 11 and 18 with loadings of 0.901, 0.782 and 0.691. These variables can be clubbed as Use of Multimedia and Non Conventional Innovative Teaching Strategies

Factor 5 is constituted of variables 6 and 5 with loadings of 0.852 and 0.741, respectively. These variables can be grouped under a single factor:

Promotion of Student Participation and Achievement

Factor 6 is constituted of variables 9 and 2 with loadings of 0.824 and 0.673, respectively. These variables can be grouped under a single factor:

Greater Emphasis on Problem Solving Skills

CONCLUSION

An appraisal of the laboratory courses in the B. Sc. Physics programme reveals that these are being received well by the students, particularly those pursuing the B. Sc. (Major) in Physics. Their success rates improve as they move from the first to the third level and their satisfaction levels are high. The reason clearly seems to be that these courses are taught in an intensive face-to-face mode. Moreover, these are perceived by academics in the conventional system to be even better as far as the course design and implementation strategies are concerned. However, further probing of learners' perceptions reveals interesting pointers on how to improve the teaching learning in the laboratory. The factor analysis of the data on learner perceptions leads to the identification of six factors as the key determinants of the quality of teaching lab courses in Physics:

- Guided approach to teaching physics, which also promotes cooperative and exploratory learning;
- Student centred learning and assessment;
- Emphasis on self learning through accessibility of SLMs (selflearning materials) and lab demonstrations;
- Use of multimedia and nonconventional innovative teaching strategies;
- Promotion of student participation and achievement; and
- Emphasis on problem solving skills.

It would be pertinent to mention here that though these pointers are interesting for improving the teaching learning in the laboratory, the findings from the factor analysis have the limitation that these are based on the perception of only the learners. Yet these findings have significant implications for the redesign, development and delivery of undergraduate Physics laboratory courses and inculcating experimental skills in self learners within the systemic constraints. Moreover, these findings can serve as useful indicators for evaluation of the quality of teaching Physics lab courses at the undergraduate level in future, provide criteria for setting up appropriate institutional mechanisms and promote convergence between conventional and open leaning.

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Appendix 1: Student Feedback related to the Laboratory Component of the B. Sc. Physics Programme

	Strongly Agree	Agree	Unsure	Disagree	Strongly Disagree
Practicals Do practicals cover key areas and ideas?					
Do they have thematic continuity?					
Does practical experience help relate theory with practice?					
Are laboratory sessions well planned and structured?					
Are they lively and stimulating?					
Academic Counsellors Did the academic counsellor explain how to perform practicals in Physics lab?					
Did the counsellor help you when you encountered difficulties?					
Did the counsellor show interest in your progress?					
As a Student Did you look forward to practical sessions?					
Did you enjoy being in lab?					
Did you learn a lot from practicals?					

Overall comments about laboratory experience:

……………………………………………………………………………………………………

……………………………………………………………………………………………………

Appendix 2: Lab Questionnaire for Physics (Major) Students

Please rate the frequency / importance with which the following statements should apply by circling the appropriate number:

Very Frequent 5 Very Important	Frequent Use 4 Important	Moderate Use 3 Moderate Importance	Occasional Use 2 Marginal Importance	Seldom Use 1 Insignificant	Never Used 0 No Importance

1. My Physics counsellor should ensure that students in the class learn the basic facts, laws and principles of Physics so that I get good grounding for later study. 5 4 3 2 1 0
2. Class instruction in Physics should stress generalized processes, which aid reasoning and problem solving skills rather than emphasize specific content. 5 4 3 2 1 0
3. One of the major objectives of Physics instruction should be the development of abilities in students to cooperate and work with peers to achieve useful outcomes. 5 4 3 2 1 0
4. The Physics counsellor should help students by using structured worksheets to guide activities and learning in Physics. 5 4 3 2 1 0
5. Student achievement in Physics should be measured by testing his ability to correctly answer specific questions in terms of established scientific facts, laws and processes.
6. 5 4 3 2 1 0
7. The academic counsellor should keep the teaching plans and work schedule very flexible to encourage inputs from students in designing investigational activities and topics to be covered. 5 4 3 2 1 0
8. In studying Physics, students should be able to obtain almost all information from sources such as class demonstrations, study materials and other supporting multimedia or library material prepared or organized by Physics counsellors. 543210
9. In Physics, the intrinsic personal rewards of self learning and finding things out independently should be stressed rather than the attainment of good grades by getting all the facts correct. 5 4 3 2 1 0
10. My Physics counsellor should provide us with situations which exemplify concepts and that require each student to figure these out for himself or herself from the examples considered. 5 4 3 2 1 0
11. Students should have the opportunity to do whatever explorations they want when working with Physics equipment, provided this is done with care and safety. 5 4 3 2 1 0
12. The instructional materials in Physics should encourage students to debate alternative notions and explanations with their peers, in addition to conventional or traditional ideas given in textbooks. 5 4 3 2 1 0
13. Counsellors should help students who do not properly learn important concepts and principles of Physics by giving them extra practice to achieve better understanding. 5 4 3 2 1 0
14. When a student proposes an explanation of his or her work contrary to an accepted fact, the counsellor should attempt to explain the error so that the mistake is not repeated. 5 4 3 2 1 0
15. My counsellor should do class demonstrations with simple equipment to illustrate the principles involved. 5 4 3 2 1 0
16. Physics counsellors should use multimedia aids such as the overhead projector, film, video, computer, etc. to present topics more vividly. 5 4 3 2 1 0

17. Physics counsellors should use a direct presentation approach to help students learn important facts. 5 4 3 2 1 0
18. Assessment should be negotiated with individuals and small groups within an agreed framework of requirements for successful completion of work. 5 4 3 2 1 0
19. Students, who are doing valuable things with their science equipment, should be rewarded appropriately in order to encourage other students for attainment of course objectives. 5 4 3 2 1 0