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Laboratory-Based Innovative Approaches for Competence Development*

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Laboratory experiences can be *powerful tools* in the engineering and polytechnic education system, since the laboratory is the primary location to develop the skills and competences that industry requires. A student is expected to work in a laboratory for 40-50% of the time. Thus, the laboratory has become an extremely important place of learning. However, at most institutions, the laboratory has often been found to be a weak link and has been a matter of concern for quite some time for various stakeholders. This has led to the realisation of the need to make laboratory work more effective by bringing in innovative approaches. Various areas of laboratory innovations that have been purposefully designed and directed to improve laboratory practices are examined in this article. Areas considered include designing innovative laboratory experiences, modifications in experimental set-up, variations in the experimental process, visual laboratory manuals, micro-demonstrations, improvements in assessment schemes, project work, etc. It was found that such innovations increased students' interest levels in laboratory work, and the experimental methods adopted were better suited to competence development. Some of these innovations, which the authors initiated, designed and developed, are being trialled in some of the technical educational institutions in India. In this article, the authors describe the salient features of many of these innovative approaches.

ISSUES OF CONCERN IN ENGINEERING LABORATORY WORK

Studies and the interaction of conscientious teachers with engineering institutions regarding laboratory work has led to the emergence of several issues. Some of the concerns are listed as follows:

- Laboratory work is organised in such a way that students do not find it useful and motivating;
- Practical work is assigned a secondary role and, as such, is handled casually by teachers and students;
- There are no well-defined aims or objectives for practical work; therefore, this results in random or disjointed work;
- Practical work indicates a lack of relevance to the job functions of graduates;
- The organisation of practical work favours the manipulation of observations due to the stereotype of experiments and students finding nothing new to be carried out;
- Industry has commented that requisite competences have not been developed in most graduating students from many of the technical institutions.

These issues indicate that laboratories at engineering education institutions need to be reviewed as they are one of the various places where relevant competences can be developed in *miniature industries*.

COMPETENCE: THE KEY

Deliver the goods, cries industry. *Give me performance, I want a targeted output,* orders the shop-floor

*A revised and expanded version of a paper presented at the 7th *UICEE Annual Conference on Engineering Education*, held in Mumbai, India, from 9 to 13 February 2004. This paper was awarded the UICEE platinum award (second grade) by popular vote of Conference participants for the most significant contribution to the field of engineering education.

manager. *Develop a workable prototype,* demands the head of the R&D section. *There should be a behavioural change* states the educational psychologist. What is this all about? It all means that everyone now requires a *tangible output* that is *observable* and *measurable*.

Industry often thinks in terms of competences that are required in order to carry out jobs. However, most of the education institutions in India produce graduates who possess generic skills (at the knowledge and comprehension levels). When industry recruits graduates, the firms have to spend a considerable amount of time and resources training new recruits before they actually start performing their designated jobs. In today's competitive world, industry requires results-oriented competent people to perform their jobs proficiently as soon as they are recruited from educational institutions.

In general, the competence necessary to perform one's job function can be defined as follows:

> *... a statement which describes the integrated demonstration of a cluster of related knowledge, skills and attitudes that are observable and measurable,* [and] *necessary to perform a job independently at a prescribed proficiency level* [1].

In other words, competence can be described as one skill built upon another, ie practical skills, cognitive skills or interpersonal skills. This is shown in Figure 1.

In order to develop the requisite competences and associated skills, the laboratory environment has always been considered as one of the best places in an engineering institution. For this to happen, similar laboratory experiences need to be provided repeatedly to students, since they cannot be developed in one go. Needless to say, learning from laboratory experiences can become manifold if the activities inside the laboratory are motivating and stimulating.

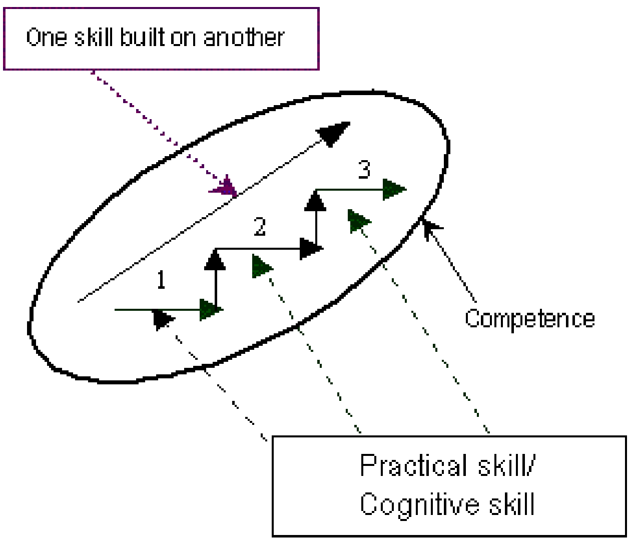

Figure 1: How competences can be developed.

THE NECESSITY FOR INNOVATIONS

Laboratory innovations render practical work interesting and challenging for both the *teacher and the taught*. Innovations in the laboratory enrich the quality and quantity of the experimental methods, as well as experiments. Generally, in engineering educational institutions, the same type of laboratory experiments (in which all the instructions are provided) are routinely carried out several times, whereby the students are not required to think and act independently. Innovations will go a long way in breaking this stereotype, but also fulfil key curricular requirements.

Innovations are commonly understood to be as follows:

> *An idea, object or practice perceived as new by an individual or individuals, which is intended to bring about improvement in relation to desired objectives which is fundamental in nature and which is planned and deliberate* [1].

In fact, any change or modification in the laboratory activity, which can be helpful in increasing the skills of students, can be considered as an innovation.

The increased participation of students and teachers can result if laboratory innovations are continuously planned and implemented. Since innovations nurture creativity, it is not only students who start enjoying working in the laboratory; but also teachers and supporting staff who are actively involved in laboratory instructional activities derive immense satisfaction spending time in the laboratory. By ushering in innovations in various areas to make laboratory work more effective, teachers and supporting staff will find their efforts more rewarding, which should result in the continuous improvement of laboratory activities and experiments.

Constant interaction with industry has revealed that the enhancement of teamwork and the development of interpersonal skills, as well as positive attitudes, must be effectively taken up by engineering institutions somehow. The laboratory is a key area for this to be achieved.

APPROACHES TO LABORATORY INNOVATION

Important approaches to innovation are those that, if planned and implemented properly, can bring about positive change by focusing on laboratory instruction. This should lead to the effective development of students' skills. Such key approaches involve the following:

- Graded laboratory experiment design;
- Modifications in experimental set-up;
- Variations in the experimental process;
- Visual laboratory manuals;
- Micro-demonstrations;
- Improvements in assessment schemes;
- Project work.

GRADED LABORATORY EXPERIMENT DESIGN

In an engineering laboratory, it is difficult to jump suddenly from a *conventional* type of laboratory experiment, wherein all instructions are given by the teacher as a teacher-centred experiment (TCE), to a *project* type or *student-centred experiment* (SCE) where students are abruptly asked to become fully independent.

As such, the concept of a graded laboratory experiment design is introduced in this article [2]. By taking a student through the following graded types of experiments, the student is progressively and purposefully made to leave his/her dependence on the teacher and become *fully competent* to handle projects independently as required in industry, rendering the transition smooth without *educational jerks* [3]. The following steps are part of this process:

- Conventional type;
- Structured-discovery type;
- Investigation type;
- Problem-solving type;
- Project type.

Of these types listed above, most engineering educational institutions have been using, in some form or the other, the first and the last type of laboratory experiments, as shown in Figure 2, ie the conventional type and the project type respectively, though they may not be called by these terms. At the extreme top of Figure 1 is the TCE, wherein students have very little freedom for adapting other alternatives. These were called the *conventional type* because this has been the normal convention in most engineering educational institutions [4].

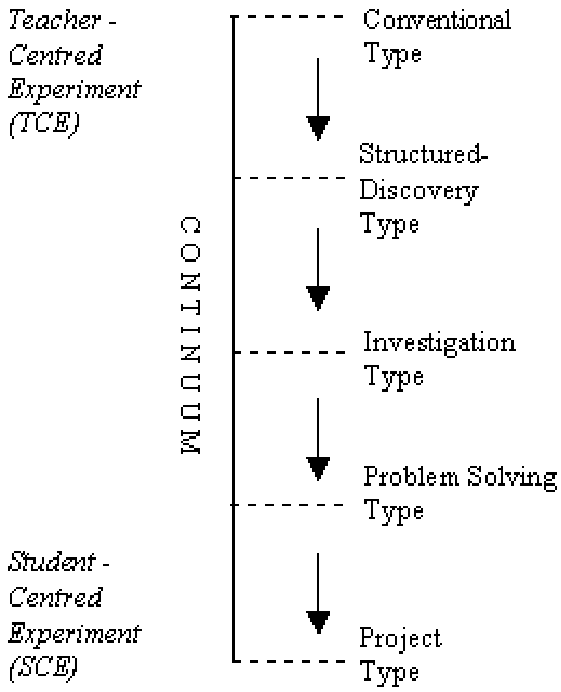

Figure 2: Laboratory experiment continuum.

At the other extreme of this continuum is the SCE, or the *project* type of experiments, in which students are given full freedom to undertake laboratory experiments and the teacher's role is that of a guide and facilitator of learning. On this continuum, from top to bottom, lie the other three different types of experiments progressing from the *structured-discovery* type to the *investigation* type and the *problem-solving* type, respectively [5].

Generally, the average students cannot cope with this sudden change from *conventional* to *project*. But, unfortunately, this is what is occurring in most engineering educational institutions. A student can be assured to become independent and thereby *competent* if the transition is smooth. This is where the role of different types of laboratory experiments, as illustrated in Figure 1, becomes relevant.

In a *structured-discovery type*, students are encouraged/guided in a structured way to *discover* for themselves the rules, laws, principles, etc, of the experiment. This is an inductive method of teaching that gives students the satisfaction and/or joy of discovering for themselves, instead of being told directly. This makes experimentation an interesting and exciting experience for students.

In an *investigation type experience*, students are permitted to make decisions on their own at various stages. This type is expected to make students *self starters* by attempting to instil in them skills of a slightly higher order. As such, the procedure can be partially structured and partially open-ended.

Problem-solving type experiences are designed to develop the problem-solving skills in students and thereby inculcate the confidence to face difficult and varied situations. When graduates gain employment or start their own enterprises, they will often encounter both small and large problems. To help the students tide over such problem situations later in life, it becomes very important to train them to solve a few problem-solving experiments during their college days in order to develop their problem solving skills and the confidence to tackle such situations.

The requisite competences could be built up gradually by purposeful design and implementation of these different types of laboratory experiments. Therefore, this graded *laboratory experiment design* was evolved to develop such skills and competences. This *new* format is structured so that every time a student looks up the laboratory manual, the competence and skills *stand out* of each laboratory experiment to remind them that the experiment is for developing competences/skills in him/her as it may relate to future careers. The format of every graded laboratory experiment includes the following components:

- Practical significance;
- Competence/skills and attitudes;
- Experimental objectives;
- Theoretical background;
- Experimental set-up;
- Resources required;
- Precautions;
- Procedures;
- Observations and calculations;
- Results;
- Interpretation of results;
- Conclusions;
- Experiment related questions;
- Assessment scheme.

Much of the details of this graded laboratory experiment design is beyond the scope of this article, but have been discussed elsewhere in some of the references.

MODIFICATIONS IN THE EXPERIMENTAL SET-UP

Innovations can be carried out in laboratory experiments by making some modifications to various equipment, set-ups, etc, eg changing the component values in electronic/electrical circuits from one experiment to the other is one example, changing the material to be tested is another, still another modification can be brought about by changing tools used in the experiment and so on. In many of the experiments, students can be provided with the opportunity to select equipment, instruments and tools to achieve the desired objectives of the laboratory work. This will help them acquire better inquiry skills.

VARIATIONS IN THE EXPERIMENTAL PROCESS

Innovative experimental processes when conducting laboratory work can be conceived by using alternative experimental strategies. Different methods can be utilised for performing a laboratory experiment. For example, water content in soil can be determined by a variety of methods, like the oven drying method, the sand bath method, the calcium carbide method, the alcohol method or the pyconometer method. Students can be asked to perform the experiment using one method and make comparisons with the results obtained using another method. Different methods can be selected for different batches of students. This would be a very good strategy for accelerating investigative skills in students.

VISUAL LABORATORY MANUAL

Explaining the use of instruments in the laboratory for certain subjects is very difficult for engineering teachers, when the group sizes of the students are large and the instruments are small. There is no doubt that an individual learns best by handling the real things. If this is not possible, provide him/her with other learning aids. The visual laboratory manual is one such aid.

The main feature of the visual laboratory manuals is that actual photographs of equipment are inserted in each experiment. The colour photographs of the real things, accompanied by black and white diagrams, helps students to learn on their own – even without the aid of a teacher – to understand how each laboratory experiment is carried out, thus promoting self-learning. This also enables the student to develop a proper understanding of equipment and identify it in the laboratory or in industry before he/she actually handles them.

Photographs of critical equipment settings, procedures, etc, render the planning of the experiment more realistic for students and, therefore, they come to the laboratory highly motivated to undertake the experiment. Furthermore, when the visual laboratory manual is computerised, it becomes all the more convenient to *zoom in* and *zoom out* certain parts of the equipment/process that the student would like to see before actually performing in the laboratory. This type of laboratory manual is particularly useful experimenting with small equipment and instruments. This manual can also be provided to students on CDs.

MICRO-DEMONSTRATIONS

Micro-demonstrations are also an effective method for developing certain complex skills [6]. The performance of students when video-recorded and viewed is a micro-demonstration to improve self-performance by receiving feedback by self-evaluation, from peers and from tutors, thereby enhancing skills acquisition. This is a very effective way to develop skills and accelerating the acquisition of experience worker standards (EWS).

Indeed, the video-recording of complex skills by an experienced industry person can be prepared; this can be viewed several times by learners in normal and slow motion. This can also aid in the development of skills in the concerned teacher and/or laboratory supporting staff, who, in turn, can then provide relevant feedback to students when they perform the same experiment in the laboratory. Sometimes, micro-demonstrations recorded in this way can also be utilised along with classroom and laboratory-based instruction so as to improve instructional effectiveness.

IMPROVEMENTS IN ASSESSMENT SCHEMES

One of the most important components in making learning effective is the assessment of laboratory work. Laboratory work is often judged by the results observed in the written laboratory reports submitted by students after experimentation, rather than evaluating the skills/competences acquired by students while they were working in the laboratory. However, the assessment scheme needs to be concerned with measuring those skills, competences and abilities that have been established as being important, and which the course concerned seeks to develop through laboratory work.

There are some skills/competences that can only be evaluated during the conduct of the experiment in *real time*; such skills are termed as *process-related* skills. There are certain other skills that can be evaluated even after the experiment is over; such skills are called *product-related* skills. Weightings for process and product related skills in each experiment need to be determined, depending upon the stipulated competences and experimental objectives laid down for that particular experiment.

An assessment scheme, if designed properly and made transparent, can motivate students to acquire skills through laboratory work in an effective manner. Innovations can be carried out in an assessment scheme for the laboratory work, whether it is formative or summative assessment. An innovative assessment scheme should cover the entire range of laboratory activities, and can be used to bring out objectivity. An example of an assessment scheme for a graded design *investigation type* of laboratory experiment on *testing an inverting amplifier* is given in Table 1.

Table 1: An assessment scheme for a graded design laboratory experiment.

Criteria considered for process-related skills (marks: 60%)		
1.	Selected the correct electronic components	15%
2.	Handled equipment, instruments properly	10%
3.	Tested performance appropriately	20%
4.	Followed safe practices.	5%
5.	Worked in the team	10%
Criteria considered for product-related skills (marks: 40%)		
6.	Obtained results to expected accuracy	10%
7.	Interpreted the results correctly	10%
8.	Drew appropriate conclusions	5%
9.	Answered the related questions correctly	15%

As the criteria are clearly stated, teachers are better equipped to assess students objectively. Also, the assessment scheme becomes transparent to students, ie students know in advance how they are going to be assessed.

Another example of an assessment scheme for a problem solving experience *identification of electrical component* is listed in Table 2.

Still another example of an assessment scheme for a *project type* laboratory experiment on the *performance of an inductive circuit* is given in Table 3.

It can be observed that the weighting for the process component in this assessment scheme is 80%, which will certainly motivate students to concentrate more on the *doing* part, thereby accelerating the development of those skills that are difficult to develop in the classroom. This method depends on the focus and design of the particular experiment; the assessment scheme needs to be designed so as to accelerate the development of the envisaged skills.

PROJECT WORK

In any engineering programme curriculum, a course on a major project is generally included in the last

Table 2: An assessment scheme for a problem solving experience.

Criteria considered for process-related skills (marks: 65%)		
1.	Probable solutions possible and derived from logical reasoning (based on discussions and initial write-up)	10%
2.	Selection from alternatives based on logical reasoning (based on discussions)	15%
3.	Plan of action properly prepared (based on written plan)	10%
4.	Implementation of plan undertaken properly and with appropriate precautions (by observation when implemented)	20%
5.	Group working and leadership role-problem centred and conflict free	10%
Criteria considered for product-related skills (marks: 35%)		
6.	Results-their justification and conclusions acceptable	10%
7.	Report properly presented all desired elements	15%
8.	Solution of problem and submission of report in time	10%

Table 3: An assessment scheme for a *project type* laboratory experiment.

Criteria considered for process-related skills (marks: 80%)		
1.	Preparation of action plan	5%
2.	Selection of proper method	5%
3.	Selection of proper resources	10%
4.	Designing the coil	10%
5.	Winding the coil	10%
6.	Testing the coil	20%
7.	Group working and leadership	10%
8.	Following safe practices	5%
9.	Recording in log-book	5%
Criteria considered for product-related skills (marks: 20%)		
10.	Report writing	20%

semester/year. However, the number of projects can be increased in order to provide opportunities to students for learning-by-doing. In order to give students a work-like experience, interdisciplinary projects with an integrated approach could be helpful and need to be encouraged.

Some laboratory-based mini-projects can be included in different semesters so that students can apply their acquired skills and attitudes. These projects could be based on small problems or a cluster of small problems, as generally evidenced in various industries. This will enable students to gain experience in solving complex problems. In this way, students will be better equipped and acceptable to industry when they graduate.

CONCLUSIONS

There could be further areas of laboratory innovations that may be thought of. The intended purpose of laboratory practices can only be achieved through continuous innovation in laboratory activities and by providing students with a *productive learning environment* so as to render the laboratory as a simulation of a miniature industry. By *productive learning environment*, the authors refer to an environment wherein students can develop their desired skills in the cognitive, psychomotor and affective domains by *performance or action*, or learning by doing.

There is a distinct need to take on the challenge of bringing in new innovations in laboratory activities on a regular basis so that they become a habit; this needs to be appreciated by all concerned. It becomes all the more important since the laboratory is an appropriate building platform for nurturing and developing competent engineering graduates with a scientific temper and the required technical skills and competences. This will help students to become more motivated to become skilled and be able to correlate effectively their classroom teaching with practical significance in a professional environment, especially industry, after their formal studies in the educational institution. The type of workforce required by industry, especially with regard to globalisation, customisation and science and technology advancing in leaps and bounds, needs to be met, thereby benefiting society.

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BIOGRAPHIES

For the last 13 years, Mrs Susan Sunny Mathew has worked as an Assistant Professor at the National Institute of Technical Teachers' Training and Research (previously known as the Technical Teachers' Training Institute) in Bhopal, India. She received her degree in Electrical Engineering and ME in Digital Techniques and instrumentation from Devi Ahilya University, Indore, India.

While at the NITTTR, she has been involved in the content updating of programmes in the areas of electrical and electronics engineering, the induction training of new teachers, the training of part-time trainers from various industries, curriculum design, research into areas of technical/engineering education, projects that have been concerned with the development of instructional material for polytechnics, engineering colleges, industry, etc. At present, she is working in the area of laboratory management.

Prior to the NITTTR, she worked as a lecturer at the regional engineering college, MANIT, Bhopal, for about two and a half years and at the SGSITS, Indore, for about four and a half years. She has been involved in teaching undergraduate and postgraduate students.

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He has a PhD in technical education from Barkatullah University, Bhopal. Dr Earnest also holds two Masters degrees: one in electrical engineering and the other in technical education from Barkatullah University, Bhopal. His area of expertise is in the area of competence-based technical/engineering education. He presently trains technical teachers from polytechnics, engineering colleges and engineers from industry in the areas of training programme design, curriculum development, instructional systems design and educational technology. He also undertakes research in several areas of technical-engineering education.

8th Baltic Region Seminar on Engineering Education: Seminar Proceedings

edited by Zenon J. Pudlowski, Norbert Gr nwald & Romanas V. Krivickas

These Proceedings consist of papers presented at the *8th Baltic Region Seminar on Engineering Education*, held at Kaunas University of Technology (KUT), Kaunas, Lithuania, between 2 and 4 September 2004. Eight countries are represented in the 29 papers, which include two informative Opening Addresses and assorted Lead Papers. The presented papers incorporated a diverse scope of important and current issues that currently impact on engineering and technology education at the national, regional and international levels. The level of Lithuanian participation indicates the nation s commitment to advancing engineering education in the higher education sector.

In this era of globalisation, much needs to be done and achieved through creating linkages and establishing collaborative ventures, especially in such a highly developed area as the Baltic Sea Region, and the KUT definitely leads the way in these endeavours. Hence, the aim of this Seminar was to continue dialogue about common problems and challenges in engineering education that relate to the Baltic Region. Strong emphasis must be placed on the establishment of collaborative ventures and the strengthening of existing ones.

It should be noted that the Baltic Seminar series of seminars endeavours to bring together educators, primarily from the Baltic Region, to continue and expand on debates about common problems and key challenges in engineering and technology education; to promote discussion on the need for innovation in engineering and technology education; and to foster the links, collaboration and friendships already established within the region.

The papers included in these Proceedings reflect on the international debate regarding the processes and structure of current engineering education, and are grouped under the following broad topics:

- Opening addresses
- New trends and approaches to engineering education
- Quality issues and improvements in engineering education
- Specific engineering education programmes
- Innovation and alternatives in engineering education
- Important issues and challenges in engineering education
- Case studies

All of the papers presented in this volume were subject to a formal peer review process, as is the case with all UICEE publications. It is envisaged that these Proceedings will contribute to the international debate in engineering education and will become a source of information and reference on research and development in engineering education.

To purchase a copy of the Seminar Proceedings, a cheque for $A70 (+ $A10 for postage within Australia, and $A20 for overseas postage) should be made payable to Monash University - UICEE, and sent to: Administrative Officer, UICEE, Faculty of Engineering, Monash University, Clayton, Victoria 3800, Australia. Please note that sales within Australia incur 10% GST.

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