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The Role of Laboratories in a Computer Technology Course*

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The role of laboratories in computer science or engineering programs has been highlighted in many curriculum guidelines, including Computing Curricula 1991, a report of the ACM/IEEE-CS Joint Curriculum Task Force. This paper reviews the different facets of such laboratory work as stated in this report. It then discusses these facets in relation to the various practice-based components of a computer engineering program offered at the Nanyang Technological University.

INTRODUCTION

IT IS INDISPUTABLE that laboratories play a significant role in computer engineering programs. The number of laboratory hours and the nature of such laboratories may differ significantly from university to university [1], but there is no question about its place in the implementation of any curriculum. In reference [2], three specific roles of laboratories are stated. The first and probably the most obvious, is the 'hands-on' experience that students receive. Be it writing a program or designing a circuit, students have the opportunity to put theory into practice. Such laboratories would counter the often-heard complaint that universities do not adequately prepare students for the application of theory to practice. Secondly, the laboratories should encourage good engineering and computing practice including the proper choice and use of techniques, methodologies, documentation, planning and tools. Lastly, there should be emphasis on formal and careful observation of results. In other words, learning is reinforced with discovery.

The paper will review the suggestions for laboratories given in *Computing Curricula 1991* (*Curricula '91*) [3] and present our experiences of implementing a practical component into our curriculum in the light of these suggestions.

BACKGROUND

The Computer Technology program in the Nanyang Technological University was conceived as a result of growing demand for computer professionals who are well-educated in both electronic engineering and computer science. The four-year curriculum, leading to an honors degree, has been designed to provide an integrated view of computer systems. The program therefore aims to produce graduates who have a range of knowledge, understanding, and skills in both the hardware and software technologies of computer systems. This involves an integrated treatment of topics including electronic devices and circuits, digital systems and computer hardware design, computer communications, programming and system software.

The core curriculum covers the requisite foundation in mathematics, programming and digital circuits. This is the basis upon which more specialised techniques and applications, which can be found in the third and fourth (honors) year options, are offered. These options reflect the key areas of technology which will be vital to the economic growth of Singapore in the future.

The program has a strong structured practical component which enables the principles and concepts taught to be applied. This, together with the compulsory six-month industrial attachment and the projects in the third and honors year of the program, emphasizes the importance attached to such practical exposure. Through these practice-oriented components of the program, students are given opportunities to apply knowledge to the task of developing solutions and in the process, promote intellectual curiosity and creative thinking.

REVIEW OF SUGGESTIONS IN *COMPUTING CURRICULA '91*

In this section, a summary of the suggestions documented in *Curricula '91* relating to laboratory work will be given. Interpretation and elaboration of these suggestions will be made where applicable.

Integration with curriculum

Laboratory exercises which have little correlation to the lecture material become a source of confusion to students. If the laboratory is to achieve

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the goals mentioned in the Introduction, there should be a strong coupling between lectures and laboratories in terms of objectives and content. The curriculum is then seen to be coherent and integrated.

Well-planned laboratory work

In order for laboratories to be effective, objectives should be well defined and the scope should be clearly specified. The assignments should be realistic [3, 4], bearing in mind the capability of the students, the background knowledge and the time constraint. Needless to say, there should be sufficient laboratory equipment to support the exercises.

Open and closed laboratories

In [3], it has been suggested that both open and closed laboratories may be used, depending on the nature of the work and the type of hardware/software involved. The basic difference between these two modes of operation is the presence/absence of supervision, and the time constraint placed on the completion of a given assignment.

Staffing of laboratories

The presence of a member of staff, be it a lecturer, research assistant or full-time technician, in the laboratories also plays an important role. Whether a laboratory is an open or closed one, it is important to have a source of help for students who encounter difficulties.

Assessment of laboratories

As in other components of a curriculum, assessment plays a dual role. Firstly, it is a means of feedback to the student as to whether the objectives of the work were attained and what improvements could be incorporated. Assessment is also used to determine whether the student has attained the standard set out by the lecturer.

Equipping laboratories

It has long been recognized that the capital investment and regular annual budgetary support for laboratories is substantial [4]. In spite of the lower costs of hardware, the cost of outfitting a laboratory has increased, with higher expectations and demands for faster, more sophisticated equipment and software. With the rapid advances in technology, institutions are hard pressed to keep laboratories up to date. Even when adequate equipment is purchased, the need to maintain the laboratories remains. Heavy usage by large numbers of inexperienced students often places a strain on equipment seldom encountered elsewhere. It is therefore not a trivial matter to keep such equipment up and running throughout the academic year.

LABORATORIES AND OTHER PRACTICE-BASED COMPONENTS OF THE PROGRAM

Laboratory experiments

Most of the courses in our four-year program have laboratory work associated with them. The only exceptions are the mathematics courses and courses such as financial accounting and industrial management. Most of the laboratory work is planned as a series of small self-contained modules (termed experiments) which can be completed in scheduled three-hour sessions. Each of these modules reflect a progressive exposure to the associated subject matter. A typical example of an experiment, taken from the Logic Design and Computer Organization course, involves the investigation of the behaviour of various logic gates. With the aid of a digital-analog training system, an oscilloscope, a digital multimeter, and appropriate IC components, students are asked to follow a set of procedures. Suitable questions based on observed results are asked throughout the experiments. The procedures get progressively more difficult, starting from a prescribed set of actions to be taken, to open-ended requirements involving the design of simple circuits. In other courses such as Operating Systems and Microprocessor Design, the laboratories are used for mini-projects which stretch across the entire academic year. Mini-projects are only introduced after the first year. An example of a mini-project has been described in [5]. On average, most students have three closed laboratory sessions per week which accounts for about 30% of their scheduled workload.

Laboratories are sufficiently equipped to ensure that work may be carried out on an individual basis. This encourages confidence in students without negating any teamwork. At times, class projects are also carried out in groups of two or three; this affords an opportunity to experience working in teams, thereby having to coordinate, plan and interact with one another. Experiment schedules are synchronized with lecturers wherever possible. This arrangement helps prevent situations whereby students are asked to carry out an experiment before the relevant theory is covered. In addition, students have free access to all laboratories whenever there are no scheduled classes. Some laboratories have extended hours of operation. All these serve to encourage weaker students to complete experiments at their own pace.

In almost all experiment sessions, a small group of students are selected for oral assessment and another group is required to submit a short formal report on the findings after the experiment. The selection of students for assessment is usually announced just before the start of that session in order to encourage students to attempt every exercise seriously. It also plays a part in the progressive training in technical report writing skills. In the case of mini-projects, all students are assessed orally and via a formal report at the end of the academic year. The laboratory work could contribute to a 'lab' course mark associated with a particular year of study or directly to the final grade of a course.

In-House Practical Training

The ten-week In-House Practical Training (IHPT) is an integral part of the first year curriculum. It is held at the end of the first academic year. Unlike the laboratory experiments carried out by the students during the first academic year, most of the work is project-oriented and the emphasis is on the practical aspects of analysis, design and implementation including construction, testing, reliability and documentation. The IHPT is designed to provide students with practical experience with equipment and software which may prove to be useful in the rest of the academic program as well as in industry after graduation.

The IHPT programme currently covers a hardware component and a software component. The hardware aspect enables students to gain some practical experience in building and designing electronic circuits and to use the computer as a tool in circuit design. This includes a mini-project which involves the process of designing, prototyping, testing and PCB fabrication of an instrument, thereby providing fundamental training for interfacing analog and digital devices. At present, the software component covers UNIX system calls, Shell programming and a Fortran programming assignment. This supplements the exposure to C programming which is taught in the first year.

Most of the IHPT is done in open laboratories. The staffing arrangement is essentially identical to laboratory experiments. In cases where specialised knowledge is involved, closed laboratories are used.

An example of this is the Electronic Computer-Aided Design (ECAD) module. Students are assessed in this part of the program through quizzes and short reports.

There are also factory and other site visits. This is to enable students to appreciate how equipment and technologies encountered in the university are utilized in industry. The visits also provide exposure to areas of large applications which are generally infeasible for class-room coverage.

Industrial attachment

The students are required to undertake a six-month industrial attachment as part of their second year curriculum. It is carried out during the latter half of the second year, after the basic topics have been covered and when students have had some practical exposure via guided experiments and mini-projects. Though not strictly a laboratory, the industrial attachment certainly contributes to the student's practical exposure. The aim of this attachment is partly to extend the skills and knowledge gained through the academic program and also to develop those skills needed to apply the knowledge in an industrial environment. The objectives of the industrial attachment are:

- to provide the student with an opportunity to apply knowledge in an industrial situation;
- to develop the social, technical and communication skills needed to work effectively as part of a team and within an organizational culture;
- to expose the student to the production, engineering and management problems of the real world and to develop the ability to appreciate and work effectively within such limitations;
- to develop the recording and reporting skills essential to a professional. The student will be able to better relate to professional issues such as Professional Codes of Conduct in his work environment.

To ensure integration with the curriculum, all proposals submitted by industrial organizations are evaluated by academic staff before they are made available for student selection. The evaluation criteria also include the availability of equipment, the suitability of the working environment, and the competence of the work supervisors. The evaluation usually requires lecturers to visit the organization and to discuss project details with the intended work supervisor.

During the attachment, there is close contact between the lecturer, the student and the work supervisor. Industrial organizations are advised to treat students attached to them just as they would their employees. The work supervisor who interacts with the student every day, provides a continuous-assessment grade. Further assessment is done by the kecturer. Upon completion of the attachment, students submit a report detailing the work achieved and the experiences gained during the six months at the assigned organization.

Final and honors projects

Major projects are carried out by students in the third and honors years. These projects offer scope to develop initiative, creativity and design ability. Both are carried out throughout the academic year with a time allocation of 10 hours and 15 hours per week respectively over three terms. Additional access to laboratories during other hours carry no penalty and are in fact encouraged. An annual student project budget is set aside for purchase of resources that are required by the projects and not available in existing laboratories.

Projects are generated by lecturers in their areas of expertise. Alternatively, they may have originated from industry. Public and private industrial organizations are invited to submit projects. A lecturer familiar with the area relevant to the project would work closely with the organization representative to supervise the student. Examples of projects include, 'A portable analog signature tester', and 'Creation of a gemstone library for a computer-aided jewelry design system'. The first project involves the development of a tester which can be used for testing components and sub-assemblies, and works on the basis of comparing the v-i characteristics of a good device against a questionable one. The latter project involves the creation of three-dimensional models of commonly used precious stones, incorporating their material textures and properties so that they can be realistically rendered.

Project supervisors interact with their respective students and monitor them as their academic year progresses. This enables the lecturer to provide an assessment of the student's ability to manage and control the project. Students are always assessed individually even though their projects may involve having to work with a partner. All students are expected to report on their findings in a formal report and through an oral presentation, both of which are assessed by supervisor(s) and another lecturer who acts as a moderator. Assessment criteria include, among other attributes, the student's ability to apply basic knowledge learned in the curriculum. Honors students are further expected to demonstrate ability to exercise careful logical analysis and independent learning. Honors projects are thus more open-ended in nature and differ from the third-year projects in that they are significantly more R&D in nature. The emphasis is on independent development and directed research. This is a means of preparing students for future research work.

FACILITIES AND STAFFING

The laboratories which support the school are well equipped with appropriate equipment. These laboratories provide an environment which enables students to carry out experiments on design and implementation, thereby enforcing the lecture-material taught throughout the program.

As a result of strong governmental support, there is generous funding for the laboratories. In both areas of hardware and software, there has been little difficulty in purchasing the latest state-of-the-art products. Upgrade of these resources has also been consistently carried out. Similarly, there is also strong support provided in terms of laboratory technicians. Each laboratory is staffed by at least two technicians whose duty is to ensure the smooth functioning of the equipment and to assist students, when necessary. This alleviates much of the work which otherwise would have to be shouldered by the academic staff.

EXPERIENCES GAINED

Although equipping and staffing laboratories have proved to be non-issues in our environment, we have found that developing suitable laboratories is not without difficulties. Integrating practical work with one's own lecture-material frequently requires interaction with other courses. A student's knowledge of certain hardware, software, techniques, etc., cannot be simply assumed. There is a need to be aware of the curriculum in its totality. Another problem is that lecturers tend to plan their laboratories in isolation, forgetting that students have to face other course-work demands elsewhere. Coordination is therefore crucial among colleagues to ensure that the overall expectation of the student does not become unrealistic. Furthermore, there is a difficulty of designing experiments that require an integrated use of hardware techniques and software methodologies in building a system.

The effort required to schedule various laboratories and In-House Practical Training sessions should not be underestimated. There is also administrative work required to supervise the projects and industrial attachments. Fortunately, the university has an industrial liaison unit which contacts organizations for student placement. Lecturers nevertheless have to authenticate the proposed placements and meet the students on a regular basis. All these tasks are time-consuming, involving somewhere around 100 hours of effort per staff.

So far, we have been fortunate in having ample placements for the six-month attachment. In spite of some places being found unsuitable, there are sufficient places left for the students. There has also been no difficulty in obtaining adequate projects for the students. However, this may change with the economy.

Assessing laboratories and other practice-based work places an extra burden on lecturers. Unless there are sufficient research or teaching assistants, which we do not have at present, the setting and marking of laboratories will take up a considerable amount of time.

From the student viewpoint, the emphasis on laboratory work requires hard work and effort to complete. The industrial attachment and In-House Practical Training takes away much of the vacation time. We are fortunate that most of the students see the long-term gain of this intensity and generally put in reasonable effort in accomplishing the tasks.

Each of the practice-based components discussed above, contributes to additional educational experience cited in *Curricula '91*. Firstly, some projects require team-work. This requires strong interpersonal skills and project coordination and management. Secondly, communication skills are developed. This could refer to the individual reporting his/her results in a laboratory log-book, or an oral presentation of his honors year project or communicating with peers in the In-House Practical Training or simply talking with his co-workers during the industrial attachment. Library skills are cultivated in the major projects. Students are expected to research the area and to be able to do literature searches on their own. Finally, awareness of the work environment and the activities of the profession is re-emphasized during the six months in industry.

CONCLUSION

Looking back at the suggestions of *Curricula '91*, in light of our experience, we feel that we have fared well where staffing, equipment, accessing laboratory work and having both open and closed laboratories are concerned. Laboratories are an extremely resource intensive component of any curriculum. In a computer engineering program such as ours, this is a gross understatement. We have had the luxury of not facing budgetary constraints, but experience has proven that having equipment and technical support does not ensure a problem-free laboratory.

Ensuring that laboratory work keeps up with the curriculum review and update, is not quite so easy. Planning ahead is crucial here, in order to ensure that the laboratory work continues to be relevant to the material taught in lectures. Furthermore, a close fit between equipment and needs is required.

Planning done in isolation leads to a situation where students face a barrage of assignments, thereby nullifying the benefits of the laboratory experiences. Ensuring that our students do not face an unrealistic amount of work is one of our greatest difficulties. This requires frequent feedback from students and regular meetings by staff, especially those teaching on the same year of the program. Only by having a global view of the workload, can we protect the program from overload. Lecturers have to be prepared to put in many hours of preparation, supervision and marking. However, this is not a high price to pay when we observe that the roles of laboratories stated above have been met.

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