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The In-House Practical Training Programme

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This paper introduces a unique way of training university students in-house in a simulated industrial environment to enhance their technical competence, experience and confidence. This in-house practical training prepares students to meet the challenges ahead when they are attached to industry and when they work in industry upon graduation.

INTRODUCTION

SINGAPORE began its industrialization programme in 1965. The original aim was to create jobs and employment for its growing unemployed population. Ultimately, industrialization has contributed to the economic development and growth of the nation.

By 1981 when the Nanyang Technological Institute, now known as the Nanyang Technological University, was established, its primary role was to train and produce more qualified engineers for the rapidly expanding industry. A large number of manufacturing and construction industries were flourishing like wild mushrooms. These organizations needed to recruit technical and managerial manpower to support their operations, but were not ready or prepared to offer the necessary training.

Hence, the universities and polytechnics in Singapore were given the task of producing the required trained manpower. Unlike developed countries such as the USA, the UK, Germany and Japan, where industries were willing and capable of training their engineers in-house and on-the-job, while the universities were primarily responsible for providing only academic training, Singapore had to rely on its educational institutions to provide graduates with practical training as well.

Therefore, we took on the task of training engineers with sufficient relevant practical experience for industry. One such training element introduced was the In-House Practical Training (IHPT) programme, which was initiated in 1983, after we had received the first intake of 582 engineering students in 1982.

CONCEPT AND OBJECTIVES

The 10-week IHPT programme became an integral part of the NTU curriculum. This entire self-contained university training programme was scheduled at the end of the academic sessions of the second-year course. Grading of marks was made compulsory and accounted for in the computation of the overall academic results leading to the award of the engineering degree.

The innovative approach of this programme injects a new perspective into the traditional gamut of classroom-based engineering curriculum. Each programme is designed so as to immerse the students in a simulated industrial environment within the NTU.

The objectives of the programme [1] are to prepare our students better:

- for their industrial attachment or co-operative programme in the following year, which is also a formal and integral part of the NTU curriculum; and
- to become competent and productive engineers soon after graduation.

To achieve these objectives, the IHPT programme must be designed to provide students with:

- experience of working in a real-life development or construction project of substantial duration and challenge;
- hands-on experience in applying theories to practice;
- general knowledge and exposure in a simulated working environment; and
- utilization of interpersonal and communication skills.

PLANNING AND IMPLEMENTATION

Each Engineering School was given ample flexibility to plan and implement its own IHPT programme catering for its specific needs. All second-year engineering students are required to undergo this ten-week IHPT programme after their year-end examination. The IHPT programme was subsequently extended for the first-year computer and material engineering students in the School of Applied Science (SAS).

Strategies

How does one plan and develop a 10-week in-house training programme in a university environment to maximize the learning potential of engineering and applied science students in a simulated industrial setting? The question will need to address several issues pertaining to a set of training and learning strategies which are further subject to other constraints.

The IHPT programme must be intensive and cost-effective and be able to inject some realism into the industrial-type exposure and training. Students must be motivated and enthusiastic to participate fully in the programme for it to be useful and successful. The programme must be sustainable over time in terms of budget availability, manpower and equipment resources, faculty and student interest and industrial relevance.

Each School has taken into account all of these strategic requirements when planning and implementing the IHPT programme. A variety of training approaches were considered, ranging from the 'single project' approach to the 'modular' approach.

The School of Civil and Structural Engineering (CSE) organizes its programme [2] based on the former training approach, by requiring the students to execute a real-life construction project. The programme offers them a unique opportunity to gain first-hand experience in teamwork, decision making, quality and financial controls, business development and in almost all aspects of planning, design and construction processes. The students are grouped into several independent 'construction companies' whereby academic staff act as their consultants and technical staff provide various types of support. The typical size of a company comprises 30 students under the supervision of two academic staff. By rotating their roles in management functions, administrative operations and site construction works, the students are involved with the following forms of training:

- Surveying and setting out
- Civil engineering planning and design
- Safety and quality control
- Quantity surveying and cost control
- Construction management
- Communication skills and marketing

The School of Electrical and Electronic Engineering (EEE) plans its programme [3] based on the combination of single project and modular approaches. There are six training modules, comprising:

- Industrial talks
- Factory visits
- Mechanical workshop
- Workstation education and programming
- Oral presentation

and a single industrial project stretching over the entire 10-week period.

Each of these modules is supervised by a group of academic staff. The overall programme is co-ordinated by a committee of nine academic staff who are involved in the preparation and execution of the training modules. Each project is supervised by two academic staff and supported by the technical staff in each laboratory.

In the School of Mechanical and Production Engineering (MPE), the programme [4] has taken the form of modules, averaging about six in the last three years. The modules offered in a typical academic year include:

- Computerized numerical control (CNC)
- Computer-aided design/computer-aided manufacturing (CAD/CAM)
- Thermal engineering
- Instrumentation and control
- Project
- Product modelling

Each group of 10 students participating in a project is supervised by one academic staff, one technical staff and one research assistant.

In the case of School of Applied Science (SAS), the IHPT programme consists of six modules and factory visits, similar in structure to those of the EEE and MPE. The six modules covered under this programme are:

- ECAD and PCB fabrication
- Unix shell programming
- FORTRAN programming
- Microprocessor interfacing
- Introduction to the logic analyser
- Basic soldering skills

Depending on the type of module, the student group size varies from an individual to a team of two and possibly up to a team of four. The student projects are supervised by the academic staff.

Training programme and typical projects

Civil and Structural Engineering. In the CSE IHPT, the prerequisite planning and design of an actual life-size construction project are executed by a team of academic staff prior to the commencement of the programme. A typical organization chart for an individual IHPT programme is shown in Fig. 1.

Each construction company or team, comprising two academic staff and 30–35 students, is given a simulated budget to complete the portion of the project assigned to it within the stipulated time schedule. All monetary transactions are simulated and monitored to check for prudent financial planning. To execute the construction project, each

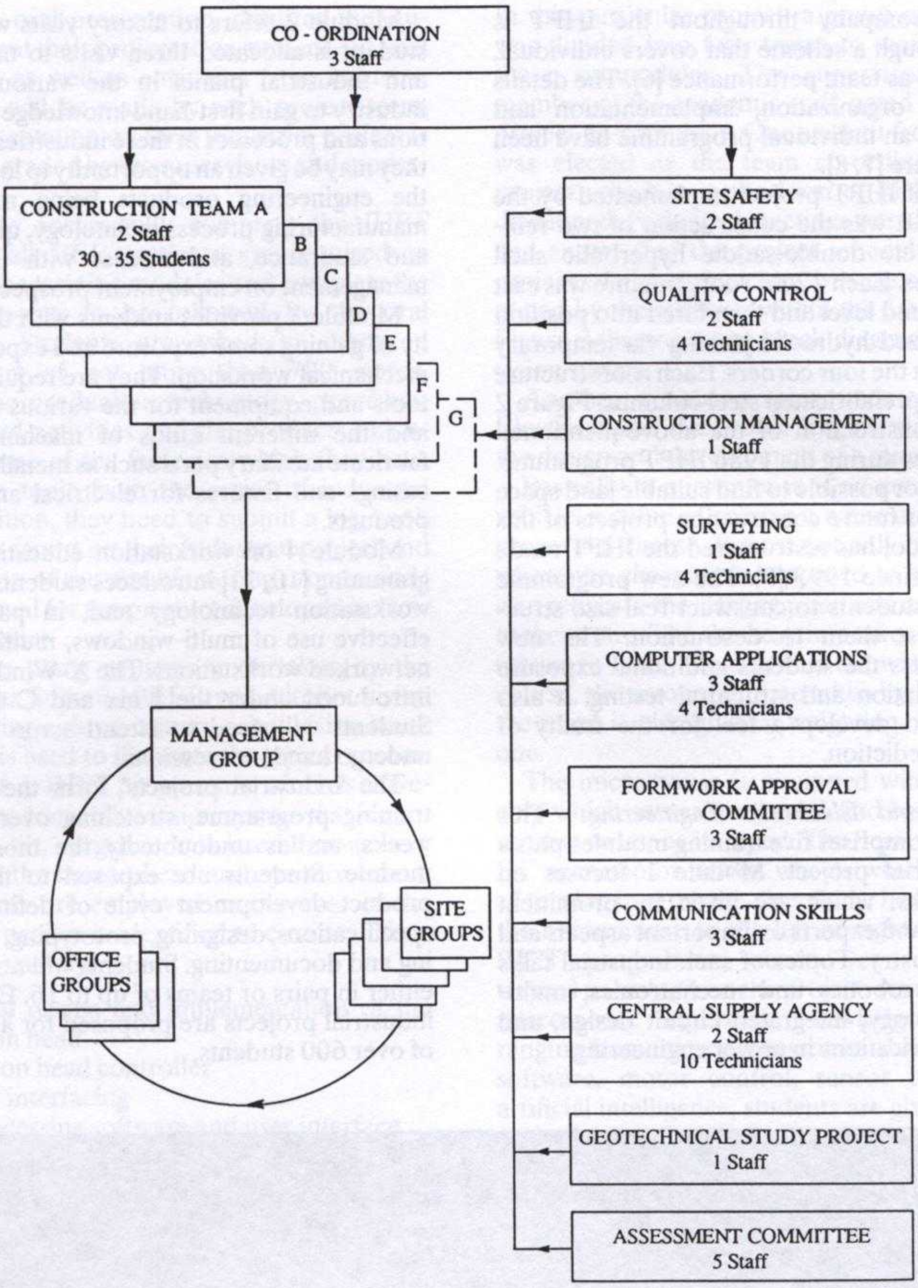

Fig. 1. Organization chart for IHPT.

company has to schedule works, make purchases, indent rental of machinery, keep accounts to ensure sound financial status and undertake construction management of the project. Disincentives of the type which commercial contractors would face are imposed for non-compliance to specifications, violation of site safety regulations, delays in construction work schedule, overtime work, late requisitions and other disruptions.

Budget overruns and delays in completion are reflected in poorer grades for the companies concerned. In the final week of the IHPT, the programme culminates in business development and marketing in civil engineering practices. Each company draws upon the experience gained from the IHPT to package a written contract bid on a construction project of a similar nature to the IHPT project. On the last day of the programme, each company is invited to make a formal oral presentation before a selection panel comprising professionals from industry and academia to win the contract offer.

The simulation exercise encompasses the various related aspects of civil engineering practices such as geotechnical investigations [5], site investigations and foundation design for the final presentation project, computer applications in design, drafting, management, etc., and interpersonal and communication skills.

Each student's performance in the different roles within the company throughout the IHPT is assessed through a scheme that covers individual, group as well as team performance [6]. The details in planning, organization, implementation and evaluation of an individual programme have been given elsewhere [7, 8].

One typical IHPT project implemented by the School of CSE was the construction of two reinforced concrete double-saddle hyperbolic shell roof structures. Each 12 m^2 roof structure was cast *in situ* at ground level and then lifted into position by synchronized hydraulic jacking via temporary steel towers at the four corners. Each roof structure rests on four prefabricated steel columns. Figure 2 shows the construction of the above-mentioned roof structures during the 1986 IHPT programme.

Since it is not possible to find suitable land space on campus for future construction projects of this scale, the school has restructured the IHPT mode of operation since 1993 [9]. The new programme requires the students to construct real-size structures and test them to destruction. The new approach offers the students additional exposure to instrumentation and structural testing. It also helps them to develop a feel for the frailty of theoretical prediction.

Electrical and Electronic Engineering. This programme comprises five training modules plus a single industrial project. Module 1 focuses on industrial talks, which are given by prominent industrialists and experts on important aspects and trends in industry. Topics of such industrial talks may include robotics and mechatronics, multimedia technology, integrated circuit design, and computer applications in power engineering.

Module 2 refers to factory visits whereby each student is allocated three visits to manufacturing and industrial plants in the various sectors of industry to gain first-hand knowledge of the operations and processes in these industries. In addition, they may be given an opportunity to look at some of the engineering products being manufactured, manufacturing process technology, quality control and assurance, and discuss with the company management on employment prospects.

Module 3 provides students with the opportunity of gaining some exposure and experience in the mechanical workshop. They are required to utilize tools and equipment for the various types of jobs and the different kinds of machinery used to fabricate auxiliary parts such as metallic and plastic casings and fixtures for electrical and electronic products.

Module 4 on workstation education and programming [10, 11] introduces students to the latest workstation technology and, in particular, the effective use of multi-windows, multi-tasking and networked workstations. The X-Window system is introduced under the Unix and C environment. Students will need to attend some lectures and undergo hands-on sessions.

The 'industrial projects' form the core of the training programme, stretching over the full 10 weeks, and is undoubtedly the most important module. Students are exposed to the complete product development cycle of defining product specifications, designing, prototyping, testing, costing and documenting. Students will normally work either in pairs or teams of up to 16. Each year, 32 industrial projects are proposed for a total cohort of over 600 students.

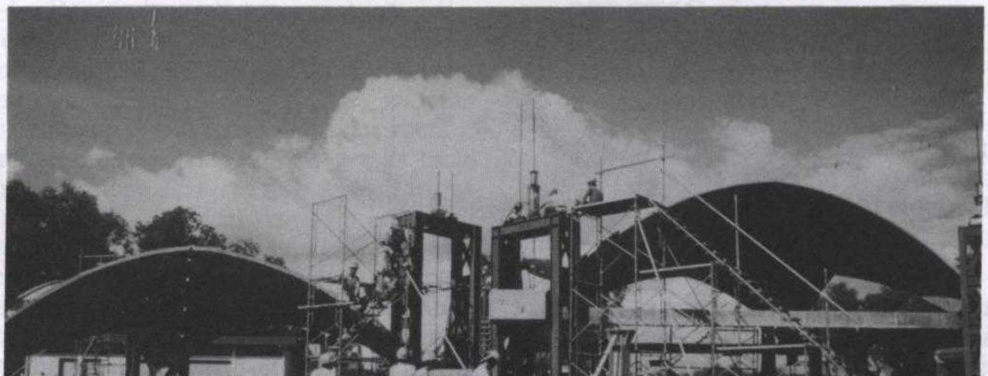

Fig. 2. Construction of two reinforced concrete double-saddle hyperbolic paraloloid shelf roof structures.

Module 5, oral presentation, requires the students to present their project to an audience of staff and students as well as engineers from industry. Presentation will be made by each project team. The oral presentation on their industrial project is assessed and graded by the supervisors and moderator.

In order to successfully complete the IHPT programme, all EEE students are required to attend all of the training modules and complete the industrial project, to be followed by the oral presentation. Students are asked to submit a written report of not more than 700 words, describing the production technology, processes, quality control activities and the products manufactured by one of the factories which they have visited and a topic from the series of industrial talks. In addition, they need to submit a log-book and a written report on their industrial project and documentation of the manufacturing process and/ or user's manual for the product developed in their industrial project.

One of the many projects undertaken by the students in the School of EEE was a 'robot vision system' utilizing a three-camera robot vision head. This project is used to illustrate the typical accomplishments of an IHPT programme, which is a five-degree-of-freedom active vision system that is capable of pan, tilt, vergence and lateral movement that mimicks the human head and eye movement. Three cameras are employed as the eyes of the system. This project is identified to consist of four submodules, namely:

- Mechanical design and implementation of the robot vision head
- Robot vision head controller
- Computer interfacing
- Image-processing software and user interface

In this particular project, a group of 16 students was divided into four teams to work on each of these submodules. The supervisor, who is a member of the academic staff, acted as the overall project co-ordinator. One student from each team was elected as the team co-ordinator. A tight project schedule in the form of PERT chart was developed. Periodical meetings were held to review and ensure that the project schedule was met. A project of this complexity was successfully completed by the students within the 10-week period. Figure 3 illustrates the block diagram of the robot vision system.

Another typical project undertaken by the Electrical and Electronic Engineering students is the design and development of a micromouse.

Basically, a micromouse is an automated robot vehicle capable of solving a maze in search of the proverbial cheese. It must not only find the centre where the cheese was supposed to be placed, but also return to the starting point and make a fast run to the centre. The shortest time taken by the micromouse to reach the centre is the winning time. Of course, the amount of time taken by it in exploring the maze is also given a weighting, albeit a lower one.

The micromouse is equipped with a computer chip which acts as the 'brain', and bank of infrared sensors to act as its 'eyes'. The 'legs' comprise two DC servomotor-driven wheels which are capable of turning in opposite directions, hence to steering the micromouse to the left or right. Through our IHPT programme, second-year students are trained to embark on the project. As the design of a micromouse requires a knowledge of expertise ranging from microprocessor hardware, computer software, motor control, sensor technology to artificial intelligence, students are given training in each of these disciplines. Many hours of hard work

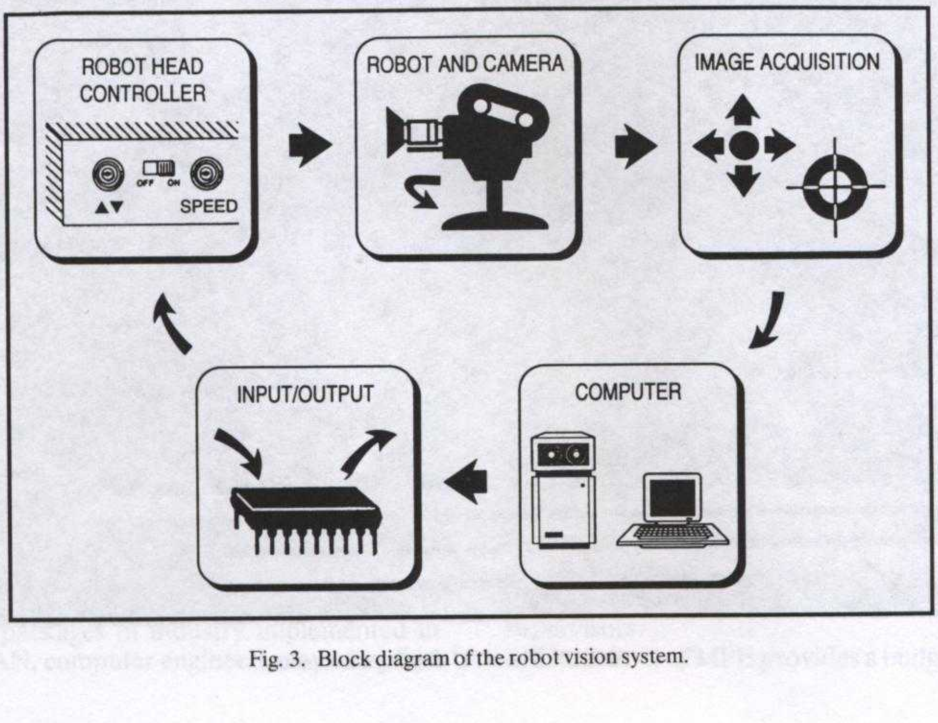

Fig. 3. Block diagram of the robot vision system.

in researching and experimenting have resulted in the evolution of five generations of micromice.

In micromouse competitions around the world, the first prize has been won twice. In London in July 1989, the students' micromouse, code-named TINEEE, shown in Fig. 4, emerged as the champion in the Euromouse Contest organized by the IEE, UK, and in October 1989 the School of EEE was victorious in the International Micromouse Contest in Singapore. The EEE student team competed against the best micromice from five other countries besides Singapore, the USA, Japan, the UK, Australia and Taiwan. The hot favourites in the contest in Singapore were MITEE from the Massachusetts Institute of Technology of USA and Noriko XX from Japan.

Mechanical and Production Engineering. The MPE IHPT [12] adopts an approach similar to that of the School of EEE. The significant difference is that the projects undertaken by the MPE students last for 3 weeks instead of 10 weeks in the case for the EEE students.

The number of projects offered in the IHPT programme varies from 36 to 45 per year for more than 400 students. These projects are in the various fields of mechanical engineering such as thermodynamics, materials, fluid mechanics, computerized numerical control, energy conversion, instrumentation and control, robotics and automation. The products related to these projects are designed and developed by the students, who also need to construct and fabricate them to meet the desired technical specifications.

The duration and training for each of the six modules can be summarized as follows:

Computerized numerical control	1 week
Computer-aided design/computer-aided manufacturing	2 weeks
Thermal engineering	1 week
Instrumentation and control	2 weeks
Project	3 weeks
Product modelling	1 week

The students are divided into their respective tutorial groups, each group numbering about 50. The six modules are then rotated amongst the tutorial groups. The modules themselves are further divided into 'station' groups. Each module may have a different number of 'stations'. As an example, the CNC module consists of the following five stations:

- Industrial metrology
- Lathe programming and operation
- Milling machine programming and operation
- EDM machining
- APT programming

Hands-on experience in industrial metrology and in the basic programming and operations of CNC machines is provided.

The project module aims to give the students an overall experience in the design, fabrication, assembly and testing of the final product. Each student is required to undertake one of the projects offered.

One typical project implemented in the IHPT programme was the 'design, fabrication and testing of an all epoxy/fibreglass composite bicycle'. Ten students were assigned to this project with the assistance of one technical staff and one research assistant.

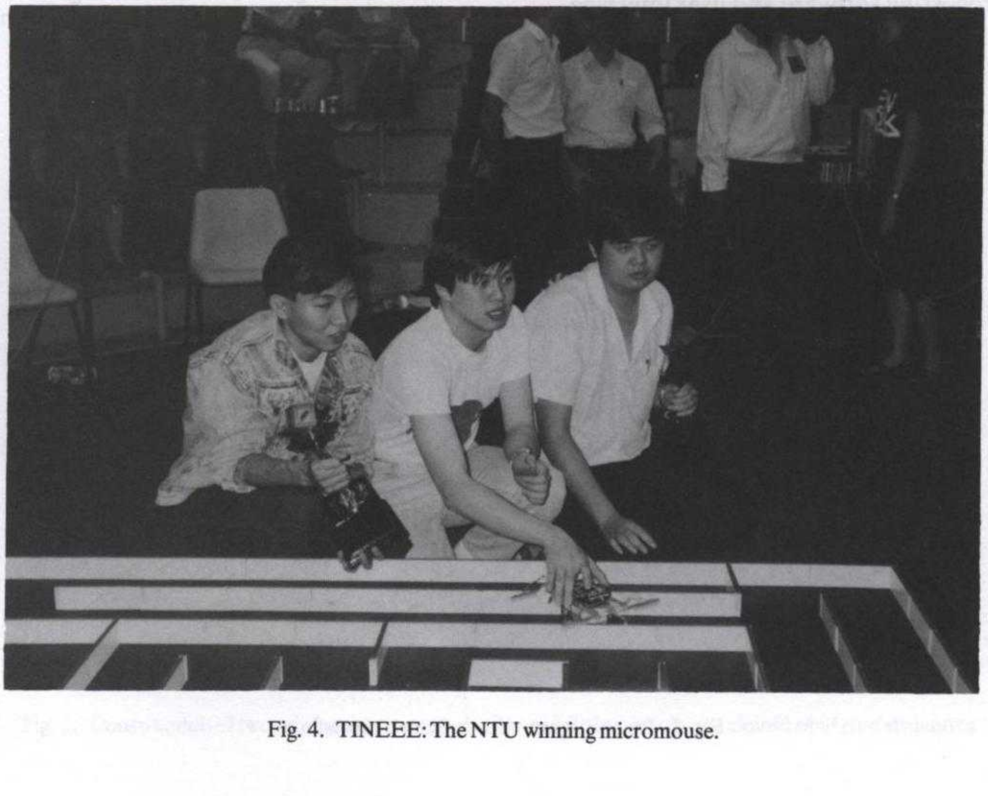

Fig. 4. TINEEE: The NTU winning micromouse.

The objectives of this project are as follows:

- To design wheels and frames for adequate strength and manufacturability.
- To design and fabricate moulds required for epoxy/fibreglass filament lay-up.
- To fabricate the actual body and wheels.
- To test individual components with possible redesign and refabrication.
- To assemble the composite bicycle.

Three groups, each led by a project leader, were responsible for the following tasks:

Group 1 Design, fabrication and testing of the bicycle frame.
Group 2 Design, fabrication and testing of the bicycle wheels and paddles.
Group 3 Logistic support group to obtain design data as well as to source and purchase items and materials.

The whole team met with the staff supervisor each morning to discuss the schedule and progress before proceeding to their own group meetings. This project took only 3 weeks to complete.

Computer Engineering. In the case of the School of Applied Science, their SAS IHPT programme is applicable to their first-year students in the 3-year computer engineering pass degree course.

The programme consists of six modules and factory visits to at least one computer technology-related company. The various modules undertaken by these students are designed to promote the integration of both hardware and software, with emphasis on practical aspects of analysis, design and construction, testing, reliability, programming and documentation.

The six modules covered under the IHPT programme [13–18] can be summarized as follows:

- *ECAD and PCB fabrication*. This module introduces students to electronic computer-aided design (ECAD) using the Mentor IdeaStation suite of software for schematic capture, digital simulation and printed circuit board (PCB) Layout. Students learn how to connect various digital logic components together and simulate their functions using the QuickSim digital logic simulation software. Students also design PCB layouts for the given digital circuit and use the FABlink software to generate drilling, milling, photoplotting and other data required for PCB manufacturing. The module is concluded with the fabrication of the PCB.
- *Unix shell programming*. Unix is the main operating system used by students throughout their course. In this module, students are taught the basic concepts of Unix shell programming and the language syntax of Bourne-shell and C-shell. This is done through lectures and laboratory assignments.
- *FORTRAN programming*. As there are many software packages in industry implemented in FORTRAN, computer engineers may often find themselves maintaining FORTRAN code. The objectives of this module are to introduce students to a second programming language and also to allow them to practise some software engineering structured programming concepts using the FORTAN programming language.
- *Microprocessor interfacing*. This module introduces students to the interfacing of analogue signals to a microcomputer and the integration of software and hardware in their system design. This module requires the students to build an analogue-to-digital converter and subsequently interface the circuit to a single-board 68000 microcomputer. They are also required to write software to read the values of the incoming analogue signals.
- *Introduction to the logic analyser*. The objective of this module is to introduce students to the fundamental operations and usage of a logic analyser.
- *Basic soldering skills*. During final-year projects and the industrial attachment, students are often required to construct electronic circuitries. The objective of this module is to prepare the students for their subsequent needs by exposing them to basic soldering techniques. This module includes a half-hour video presentation and several hours of practical hands-on soldering.

One typical project undertaken by computer engineering students from the School of SAS referred to the enhanced microprocessor-based telephone bill accounting system. This project involved the design and implementation of a telephone bill accounting system which is capable of monitoring the telephone bills of multiple users. Security measures are incorporated into the system by means of a unique password for each subscribed user. The system also provides a database to keep track of each user's monthly bill.

The telephone bill accounting system was implemented by using an 8-bit 1 MHz microprocessor which is interfaced to a dual-tone multiple frequency (DTMF) receiver and six 7-segmented LED displays. Figure 5 illustrates the completed version of the printed circuit board assembly for the electronic telephone bill accounting system.

Budget

Each school utilizes funding from its teaching budget to finance the IHPT programme.

In the case of the School of CSE, a centralized budget is allocated to the programme for the life-size construction of, for example, the reinforced concrete double-saddle hyperbolic paraboloid shell roof structures.

For the School of EEE, a budget allocation of S$600 is made for each project team of two students. The students may procure components, parts and materials for their project through the assistance of the technical staff but with the approval of the academic staff who are their project supervisors.

The School of MPE provides a budget of S$400–

Fig. 5. Printed circuit board assembly for electronic telephone bill accounting system.

500 for each of the student projects as well as some additional funding for consumable items to be purchased for the programme.

The expenditure incurred during the IHPT by the School of SAS for the running of the laboratory sessions and special projects are allocated by the respective laboratory where the module is conducted.

Overall, depending on the type of projects and size of the student cohorts, the budget allocation for the IHPT programme varies from S$120,000 to S$180,000 per school annually. This quantum translates to approximately S$300–800 per student.

However, it must be highlighted that some of the student projects undertaken during the IHPT programme are utilized as laboratory teaching aids and/or components, such as the 1 kVA single-phase and 3 kVA three-phase transformers in the School of EEE. Other student projects pertaining to manufacturing processes and automation which are sponsored by industry are being incorporated into their production floors by some of the companies. On the other hand, the reinforced concrete double-saddle hyperbolic paraboloid shell roof structures built by the students of the School of CSE have been converted into an experimental station for the school's coastal research activities.

Manpower deployment

The IHPT programme requires large manpower resources for successful implementation. The main reason for this is the high cohort of students in the scheme each year. The number of students ranges from 150 in the School of CSE to over 600 in the School of EEE.

The manpower deployed by each school can vary from 40 to over 200 each year. The chart in Fig. 6 shows how the composition of academic and technical staff from 1989 to 1993 utilized for the IHPT programme in the School of MPE ranged from 150 to slightly over 200 to support a student cohort of 300–400 over the same period. In this case, the academic staff to student ratio is around 1:4. In the other schools, the academic staff to student ratio may vary from 1:5 to 1:10 depending on the availability of resources, the complexity of the projects and the student cohorts. These ratios do not take into account the non-academic support staff inclusive of the technical staff.

GRADING AND ASSESSMENT

A comprehensive scheme of assessing and grading student performance during the IHPT programme has been devised by each school. As this programme is compulsory for all participating students in their respective schools, their training is graded. Marks are awarded to students and these are computed in their overall academic results.

Grading of the marks takes into account some or all of the following major performance criteria:

- Teamwork
- Personal behaviour, discipline and punctuality
- Work attitude
- Practical ability
- Quality of work
- Work performance
- Progress report
- Project report
- Oral presentation

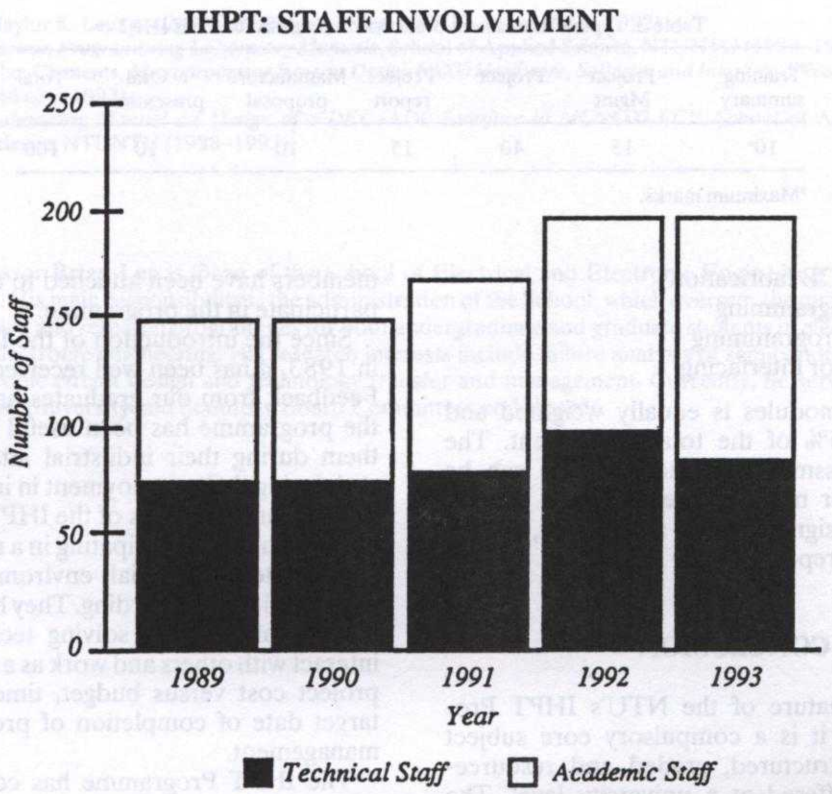

Fig. 6. Use of manpower for the MPE IHPT programme.

This list of performance criteria is not exhaustive as other factors may be considered by each of the schools.

A typical schedule of assessment for the IHPT programme of the School of CSE is shown in Table 1. Marks are allocated for individual, group and/or team performance whenever applicable. For the schools incorporating the modular approach, the School of MPE stipulates that all the modules in its programme carry equal weighting in the allocation of marks. But the School of EEE places more emphasis and significant weighting on the industrial project. Its typical assessment breakdown of marks is shown in Table 2.

Although the School of SAS offers six modules, only four of these modules are assessed, namely:

Table 1. Typical schedule of assessment for CSE IHPT

	Items	Frequency	Weighting (%)
(a)	*team performance*		
	Quality of work	weekly	5
	Cost control	once	5
	Documentation of work	once	5
	Final presentation	once	5
	Geotechnical project	weekly	10
	(Sub-total)		(30)
(b)	*Group performance* (During management week)		
	Planning and scheduling	weekly	5
	Implementation of plans and schedule	weekly	10
	Progress report	weekly	5
	(Subtotal)		(20)
(c)	*Individual performance*		
	Diary of project	once	15
	Oral presentation during weekly progress meeting	weekly	5
	Contribution to the team	once	10
	Technical and managerial skills	once	10
	Observance of safety regulation	entire period	10
	(Subtotal)		(50)
	(Total)		(100)

Table 2. Typical assessment breakdown of marks for EEE IHPT

Training summary	Project Mgmt	Project	Project report	Manufacture proposal	Oral presentation	Total
10[a]	15	40	15	10	10	100

[a]Maximum marks.

- ECAD and PCB fabrication
- Unix shell programming
- FORTRAN programming
- Microprocessor interfacing

Each of these modules is equally weighted and accounts for 25% of the total assessment. The method of assessment for each module can be based on one or more of these grading factors: programming assignment, oral assessment, written quiz and formal report.

CONCLUSION

The unique nature of the NTU's IHPT Programme is that it is a compulsory core subject which is well-structured, graded and resource-intensive and offered at a university level. The students have found the programme to be self-fulfilling, interesting and challenging and have benefited much from the training.

The success of this programme can be seen from the perspective that students have gained good technical and working experience and that a few regional universities have emulated our IHPT programme. In fact, some of their academic staff members have been attached to us to observe and participate in the programme.

Since the introduction of the IHPT Programme in 1983, it has been well received by the students. Feedback from our graduates has confirmed that the programme has been useful and beneficial to them during their industrial attachment training and during their employment in industry.

The learning values of the IHPT Programme for the students by participating in a real-life project in a simulated industrial environment have been worthwhile and rewarding. They have learnt to gain more confidence in solving technical problems, interact with others and work as a team, learn about project cost versus budget, time scheduling and target date of completion of project and project management.

The IHPT Programme has contributed to the student technical competence and judgement and will help to enhance their future professional career development.

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