STUDY OF CDIO WORKSPACES IN SINGAPORE POLYTECHNIC

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ABSTRACT

The CDIO Framework calls for the development of appropriate workspaces that support and encourages the learning of product or system building, disciplinary knowledge and social learning (Standard 6). A study of different workspaces used in the teaching of Design & Build and CIE project modules in the Singapore Polytechnic was undertaken. These workspaces are primarily used to teach modules which have Learning Designs that involve students working in teams to Conceive, Design, Implement (prototype) group projects. Particular focus was placed on how such workspaces contribute to and enhance student learning and social behavior which leads to desired learning outcomes. Students and teaching staff were surveyed to find out their satisfaction with each workspace with respect to their teaching and learning outcomes. The merits and demerits of each workspace were also discussed. Lessons drawn from this study were abstracted and recommendations made regarding the design of future workspaces.

KEYWORDS

Workspace, Learning Environment, Design-Build Experiences

CDIO PROJECTS

Many institutions invest huge amounts of resources building workspaces to support project work. While some like the Integrated Learning initiative at Queen's University, Yumekobo at Kanazawa Institute of Technology (KIT) and MIT have well equipped and large infrastructures; many projects are built in smaller laboratories. How then do we design a workspace that incite and support the CDIO project? Can the project workspace provide a refuge that systematically cultivates teamwork and synergy amongst members?

A close examination of workspaces reveals that most projects happen amidst 4 elements:

- CDIO process
- Environment
- Tools used in projects
- Students' interaction

These elements interact in different intensity at various project stages with students' interaction residing at the heart of all these elements as shown in Figure 1.

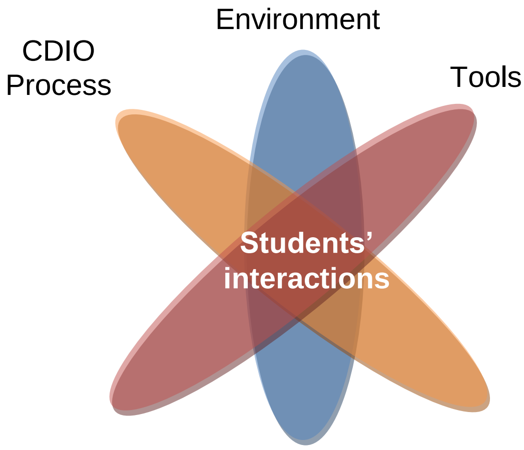

Figure 1. Elements available in CDIO Projects

To understand how workspaces can be better designed, it is useful to first dissect the activities that transpire in the workspace and how they interact with these elements. Understanding the activities that take place during the different phases of the project is thus useful as it helps to map out the students' interactions and thereafter translate them into the different needs of the workspace.

CDIO Process

Table 1 shows the activities that take place at the various stages of the CDIO process. It can be seen that some of these activities involve more group work while others are carried out by individuals.

Table 1
Project Stages and Activities

Project Stages	Activities
Pre-Project	Form effective teams
Conceive	Research Create concepts Generate and share ideas
Design	Translate concepts into tangible design Develop potential solutions Combine building blocks Prototype ideas using simulation or other means
Implement	Fabricate parts Assemble parts Test integrated project Troubleshoot project
Operate	Demonstrate workability Execute tasks

In the conceive stage, students typically discuss and generate ideas. Thus, the workspace needs to provide furniture and resources that support collaborative work. In contrast, the design and implementation stages require students to work individually while keeping tabs on what other team members are doing. Many problems arise if students fail to communicate effectively over these stages as they may end up with completed parts that cannot be successfully assembled or integrated. Workspace infrastructure to support information sharing and communication is very important to ensure the success of these 2 stages.

While some students can continue to use the same workspace to operate the project, others may require another space. In one Year 2 CDIO project, the completed aircraft model had to be operated in a stadium as the enclosed workspace cannot handle this activity.

ENVIRONMENT & TOOLS (WORKSPACE DESIGN)

Many papers have stressed the importance of flexibility, 24/7 access, availability of tools etc, in workspace design. We will focus instead on designs that facilitate the interaction among project team members while conducting projects. Three parameters found to be crucial in promoting interaction are :

- Furniture
- Vertical visualisation support
- Information management

Furniture

As mentioned previously, students work in groups during some stages of their project work and individually in others. The workspace has to offer sufficient flexibility so that where both collaborative and individual work can be carried out. This can be implemented using reconfigurable furniture. However, if furniture has to be rearranged, it should be ensured that this can be carried out smoothly without too much time being expended.

Another important consideration is for project workspace to be flexible enough to be used for secondary purposes like the conduct of lectures, seminars, tutorials etc. Many a time, project workspaces are designed for students to work in clusters. They may not be ideal places for lectures.

Vertical Visualisation Support

A picture paints a thousand words. It is therefore essential for students to be able to share ideas and discuss using images besides words. Vertical visualisation using a whiteboard or flipchart is very useful for students to express and discuss their ideas.

A common problem encountered in a project workspace used by many groups of students is in capturing and storing information discussed. Students usually capture notes from whiteboards after discussion by copying them on pieces of paper. With the advance of technology, some workspaces have digital smart boards that can store data and print information drawn on them easily.

Students' Information Management System

Throughout a project, students generate a lot of ideas and information. Since the CDIO process is linked and activities carried out in successive stages are highly related to previous ones, it is crucial that documentation is properly and effectively kept. Failing to do so will result in students making mistakes and having to repeat their work.

There are generally two streams of information that flows throughout the project; the recording stream that is generated based on analysis and the creativity stream that is based on generative activities such as synthesis and exploration as shown in Figure 2.

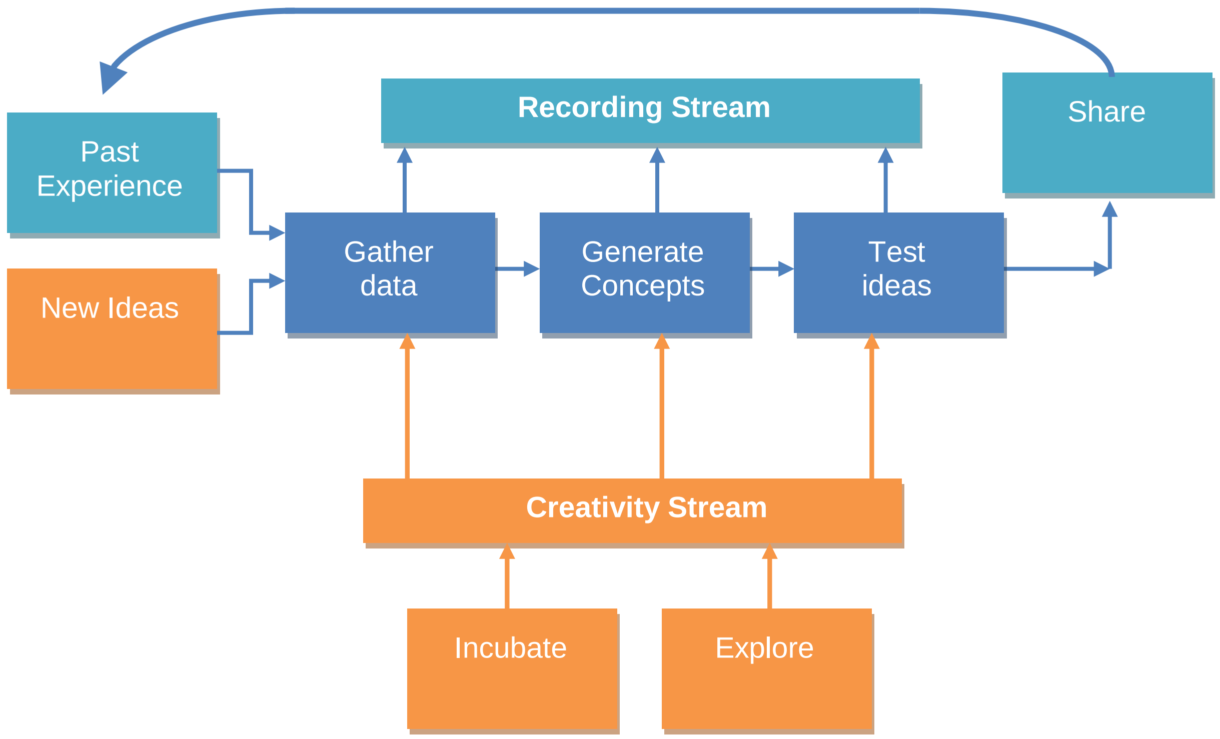

Figure 2 Streams of data derived from project

It is important that project workspaces facilitate these streams of information and is also able to capture them effectively for students to refer to them in subsequent stages of project.

WORKSPACE DESIGN FOR ELECTRONIC PROJECT FABRICATION

DESIGN & INNOVATION PROJECT (D&I) LAB AT T822

The lab at T822 was designed for Year 2 Design & Innovation Projects. Three groups of students from the Diploma in Electrical and Electronic Engineering made use of this lab to build their projects. Depending on the options that students had subscribed to, the projects could be aerospace, microcontroller or bio-electronics related. Activities carried out in the lab ranged from conceiving what the final artefact should do, to the fabrication of chassis and electronic circuits.

The workspace was designed to support students operating in clusters of 4 to 5 students. In each cluster, there was some standard furniture and equipment such as power supply, oscilloscope and soldering iron available for students to complete their projects. Students generally made use of their assigned area as their base stations that also included storage areas and also some vertical spaces for discussion usage. Wireless LAN is available in this lab to allow students to surf the internet for information related to their projects. Lab PCs were also made available for students to program their projects with the necessary software such as Labview and C pre-installed.

Besides clustered areas, there were also several centralised locations for project use. Some of them were for keeping items such as electronic components and space with bigger equipment that could not be so easily duplicated. There was also a centralised location for students to test out their projects such as the playing field for the micro-controller robots. While most of the project activities could be carried out within the individual cluster, many students were also required to make use of an adjacent workshop to fabricate their chassis. Many machine tools for fabricating chassis were made available. The Technical Support Officer had to brief the students before they may make use of the machines. As safety is a major concern, a staff member had to be present whenever students worked in the workshop.

In addition to Year 2 students working on the D&I Projects, many final year students also made use of the workshop and workspace at T822 for free access. We noticed that third year project students liked to use this space as it had been equipped with the necessary mechanical and electronics equipment to support their projects. On the other hand, this workspace had not been successfully used as a lecture or tutorial venue.

Conceive. Students generally gathered around their clusters to discuss and generate project ideas. However, it was noted that students did not usually discuss with all their group members. It was observed that most students discuss in pairs or trios. The board that was catered for students to sketch their ideas while they discussed was not used as extensively as we originally envisaged. The workspace in T822 may not have been designed well for the conceive stage.

Design. During the design stage, students need to discuss about how they want to fabricate their projects. However, most of them did not plan their project in detail before they start. Many students just proceeded to the implementation stage and many of them encountered problems as they started to develop their projects.

Implement. Programming and fabrication were obvious activities that students carried out while they were in the implement state. Students made use of the computers in the lab and also the instruments found within their clusters to build their projects. The workspace was well designed for this stage and in fact, many students who have proceeded to their third year of course continue to use this lab due to the user-friendliness of the space. The space supported individual work where students built their hardware and carry out programming.

Operate The lab space could be used for demonstrating that the project worked as planned. As the lab was a confined space, some students who built the aeroplane models had to test their aeroplane models in the stadium. The lab space was good for students testing out their microcontroller robots and Labview biomedical projects.

So far, we noted that the space at T822 had been designed well to support the Implement – Operate stages. However, we felt that it might not have been as effective for the Conceive – Design activities as the space does not encourage face-to-face interaction and discussions.

INTRODUCTION TO ENGINEERING & IDEA (IE/IDEA) LABS AT T12601-T12606

The IE/IDEA labs were designed to teach 1st year students the creative idea generation process through a module called IDEA, and to allow them to design, implement and operate simple projects through the IE module. In both these modules, students work in teams of varying sizes at different points in time. They engage in activities that are varied, including brainstorming, pair-share-square and larger group discussions, class presentations and the designing, simulation, building and troubleshooting of electronic circuits. To accommodate this, trapezoidal-shaped furniture was selected that could easily be reconfigured for different group sizes and activities. A raised floor was installed in the lab so that electrical power can be flexibly supplied to each table cluster wherever in the room they may be. Lighting installed ensured uniform brightness and minimum shadows throughout the workspace.

The IE/IDEA labs were designed to be self contained – a one stop centre where students can go through the 2 modules in one location. Because these labs were also used by students to build and test physical projects, they had to accommodate the use of different tools and equipment required. Adequate space had also to be available for sufficient amounts and variety of electronic components to be stocked and projects-in-progress to be stored.

Another important consideration for the IE/IDEA workspaces was that they had to be attractive, vibrant and youthful in appearance. This will enable students to identify emotionally with the workspace and be proud to be associated with it. Bright colour schemes, warm lighting and an attractive ceiling grid were installed. Whiteboards were placed in strategic locations for students to cluster around and discuss ideas. An electronic SMART board was installed to up the cool factor and give flexibility to the lecturer teaching in front of the class. It also provided the option of storing discussion ideas etc easily. Wireless internet access and a wireless projector were also made available. With the latter, students are able to present their ideas to the class from where they are seated using their Notebook computers.

While the primary use of the labs is described above, the workspace had to be flexible enough to accommodate other secondary uses. This included being able to be a venue for seminars, short courses, tutorial classes and other project modules. They were also to be used as alternative venues to host our outreach programs to secondary school students.

The workspaces hosted up to 8 student classes. The following is a description of how the workspace was used in the Conceive-Design-Implement-Operate cycle.

Idea Generation (Conceive). Students formed groups of 5 to learn about the creative process and tools required for the creation of new product ideas. For this activity, tables were arranged in a configuration that could accommodate larger group discussions. They were placed next to white boards which we envisaged would be used in the discussions. However, like in T822, whiteboards provided in the lab were observed to be seldom used. Students did not like that they were unable store information on the boards easily for future use. They preferred instead to gather around a piece of paper and discuss their ideas there. The whiteboards were extensively used, however, when the instructor was involved in the group discussion – giving inputs and fresh ideas to the groups. The seating arrangements were observed to be satisfactory and it encouraged group discussions and dynamics. The deliverable of the idea generation process was a class presentation of a new and novel engineering based product or service. Students were observed to present from either the front of the class or from their discussion tables using the wireless projection system.

Design. 2 projects were prescribed to students in the IE module. They were required to work in pairs for the 1st project and in groups of 4 in the 2nd one. The projects were carefully selected to integrate knowledge learnt in supporting 1st year technical modules like Digital Electronics, Principles of Electrical & Electronic Engineering and Teamwork & Communication Skills. While the projects are prescribed, students nevertheless have the flexibility to design the projects' circuits in different ways. They were expected to verify the workability of their designs using circuit simulation and/or breadboard testing. Circuit simulation software was available in the polytechnic's servers and students can run them using their own Notebook computers through the campus wireless network. The tables in the lab were arranged to accommodate the smaller group sizes in this activity. It was observed that the design process involved mainly individual or paired work. This worked well in the 1st project as it was done in pairs. In the 2nd project, it was found that half the group was not active in the activities.

Implement. Implementing the IE projects involved the fabrication of prototype circuits on strip-boards and troubleshooting them. After that, different boards were integrated together and tested to ensure that the whole project works. This involved soldering work and the use of test equipment like power supplies, multi-meters and oscilloscopes. Heat resistant boards were used during soldering to protect the workbench from heat damage. Suction fans were installed to suck poisonous solder fumes out of the room. To avoid cluttering the workbench, students go to equipment stations at the corner of the lab to obtain and carry required test equipment back to the workbench to use. They are returned back to the equipment station when done. Despite this arrangement, overcrowding of the workbench often occurred, especially in the 2nd IE project when students work 4 to the group. Like in the design stage, project implementation was observed to be either individual or paired work.

Operate. Unlike in T822, operating of the IE projects was done exclusively in the IE/IDEA labs. One of the IE projects involved a vehicle going under and counting the number of gantries encountered. The lab was flexible enough to be configured to accommodate the testing track for this. The other IE project could be operated from the workbench. Nevertheless, projects that were not suitable to be operated from the lab, e,g, a solar car project, could be operated from venues adjacent to these labs.

Other important considerations for the IE/IDEA workspace include easy access after scheduled hours and the availability of a wide variety of electronic components and tools. All the IE/IDEA labs were treated as a common resource and were made available for free access regardless of where students are timetabled for their formal lesson. The labs were kept open in the evenings provided more than 10 students requested for the service. Each lab stocked a good quantity and variety of basic electronic components which students can draw with the approval of their lecturers. Lab technicians were also authorised to draw more uncommon components for the students from the main EEE store. Mail order component catalogues were also made available in labs should students wish to purchase them for themselves.

WORKSPACE DESIGN IN MECHANICAL & MANUFACTURING

MACHINE DEVELOPMENT CENTRE (MDC) AT W1112

Design should be learnt in a dual environmental setting; 1) in an academic and 2) in an environment simulating industrial realities. The latter is important because conceiving and designing systems and products is a creative process that is best endeavoured in a realistic environment. The MDC at W1112 was renovated precisely to engage industrial realities. The workspace is compartmentalised into sections where disciplines like design, assembly, logistic, electrical and programming take place. Infrastructures like an engineering workshop, store, meeting room and office equipment are also present to facilitate the centre’s activities. Equipment in the workshop are permanent fixtures and the student and staff activities are centred on achieving the physical outcomes. This workspace design is shown in Figure 3

Students are assigned to different parts of the workspace at stages of their project where teaching staff teach them about industrial automation systems.

Conceive. The conceive and design workspace in the MDC comprise of two rows of tables equipped with computing and general office equipment. Students sit as they would in an open office system. They are surrounded by cubicles where the centre’s staff are located (see Figure 4 for layout). Machining concepts and design details are the main components shared and discussed at this stage. The setting here emphasizes objective teaching where guidance is given in a formalised way. Blue sky conceiving exercises are not required as work in mechanical engineering designs are renovated or reused from known systems

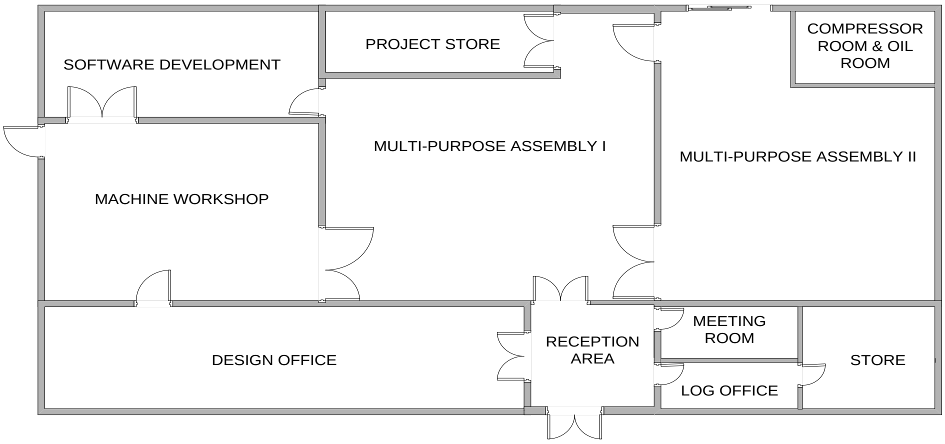

Figure 3 The MDC workspace in W1112

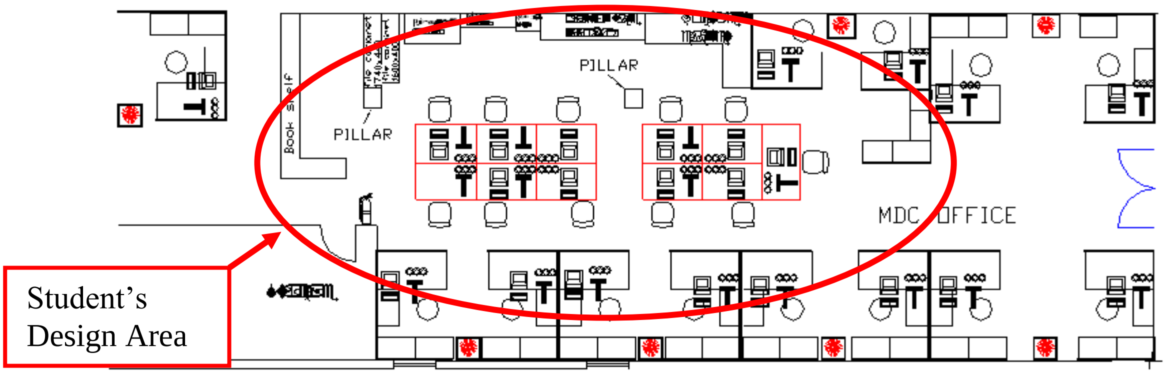

Figure 4 Layout of Design Office

<u>Design.</u> Students are required to learn appropriate design software before they proceed to the design stage. Computing systems in the workspace are loaded with design software such as AutoCad from Autodesk, Pro-E and Solidworks. Students remain in the Design Area and are given 2-3 weeks to pick up the required software skills before they are asked to model and extract parts from an assembly drawing assignment. Deadlines are given and students work out their own schedules which they must adhere to strictly.

<u>Implement.</u> In this stage, the physical artefact arising from the conceived machine specification is built. This takes place in the multi-purpose assembly areas in Figure 4. Students have to manage the space allocated effectively because although individual components are built in a modular form, the physical outcomes of the design can be as long as 25 metres. Each of the MDC's machines assembled rarely comes in the same configuration, complexity and size. The centre is equipped with enough flexibility to cater to this diversity. The predominant form of learning here is skill-based learning. See Figure 5 for the type of machines that it can accommodate.

Figure 5 Workspace accommodating different outcomes in Industrial Automation.

Operate. Students have to equip the machines built with configurable programs which can be customised using computing interfaces like touch screens. They have to master the controls and operational aspects of their machines and are expected to impart their knowledge to end users during the commissioning period. The operate stage of the project is done in the multi-purpose assembly areas

INTEGRATED PROJECT CENTRE (IPC) & PROJECT LAB AT W1113 & W1218

The IPC at W1113 and the Project Lab at W1218 are used as workspaces for the School of Mechanical & Manufacturing Engineering's IDEA and Introduction to Engineering (IE) modules. Note that this is different from the IE/IDEA labs in T12601-T12606 above which used by students of the School of Electrical & Electronics Engineering.

The conceptualising and design stage is done in the IPC while the Project Lab is used to Implement and Operate the projects. The layouts of both workspaces are shown in Figure 6 and 7.

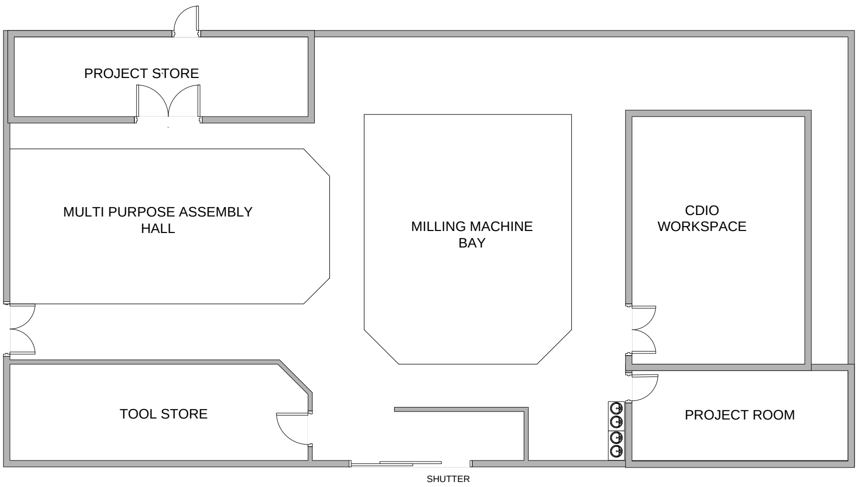

Figure 6 Project Lab in W1218 (Workspace for Implement and Operate)

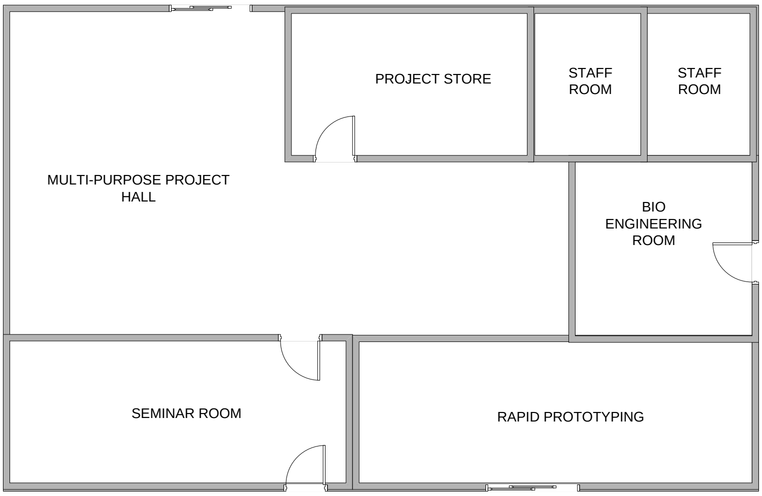

Figure 7 IPC in W1113 (Workspace for Conceive and Design)

Following the early success of the MDC, the IPC was built as a flexible workspace that supports several modules and functions including being used as an exhibition area for Final Year Projects. As such, it is not equipped with heavy and fixed machinery and can only support the Conceive and Operate stages of the IDEA and IE modules. This takes place in the Multipurpose Project Hall (see figure 7). A pictorial view is also illustrated in Figure 8.

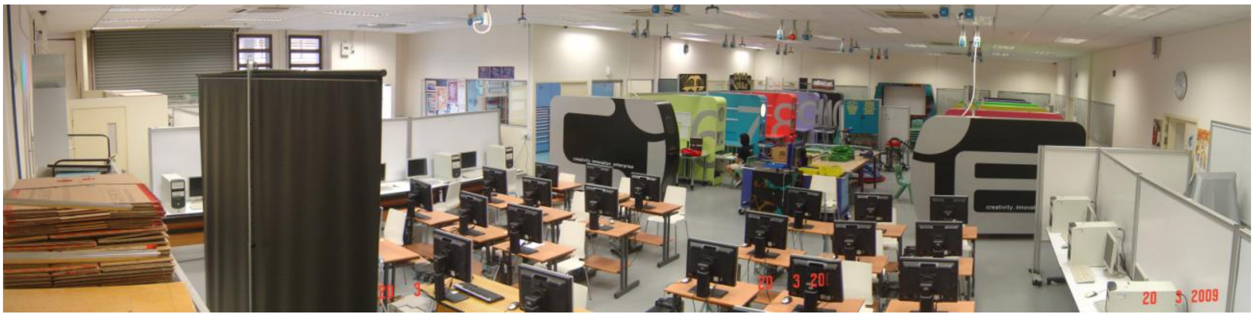

Figure 8 IPC Multipurpose Project Hall (Workspace for Conceive and Design)

Conceive. The IPC accommodates one class of 20 students at any one time. A total of 160 students or 8 classes of the IDEA and IE module are timetabled here. In addition, this workspace also accommodate about the same number of students from a different module. Students using the IPC are assigned an area designated for team usage such as discussions and project launch. Each area has facilities like PC point and chart pin up wall for their projects. These cubicles are configurable into different forms depending on needs.

Design. Students are provided with and are expected to use Studio Max and AutoCad software in the design stage of their project. The predominant activity here is team discussion and design work. This can be done either on or off campus as students now own their own laptops. The design work will be reviewed in this workspace by the module lecturer for the class.

In contrast to the IPC, the Project Lab at W1218 has many fixed supporting infrastructure like machine shop equipment including lathes and milling machines. It is also equipped with fabrication equipment for various engineering materials like Aluminium, Steel, Engineering plastic and many others. This makes it suitable for Implementing and Operating projects.

However, it is not as flexible a workspace as the IPC. The workspace layout can be visualised in Figure 9.

Figure 9 Project Lab in W1218 (Workspace for Implement and Operate)

Implement. Implementing the IDEA and IE project involves fabricating mechanical parts using machine tools and assembly work. As the IPC is not designed to house these machine tools, the project lab in W1218 is used instead.

Operate. Students also use W1218 to operate their projects. As the student artefacts derived from this module are generally no bigger than an A3 paper, they can be tested and operated upon in the limited space available in the lab. The facility has also an auxiliary storage space or cabinet to allow students to keep their projects. However this storage space is scarce and priority is given to final year project students.

User information for the MM Workspaces

School of Mechanical and Manufacturing				
Workspace Name	Location	Sq Area (M^2)	Courses (CDIO)	No. of Students
Integrated Project Centre	W1113	245	SP0502 IDEA MM1028 IE	160 160
Machine Development Centre	W1112	1125	MM3008 Teaching Factory	80
Project Centre	W1218	812	EC1166 Design & Fab Project MM305Z Project Part II	80 400-500

LESSONS DRAWN

3 lessons can be drawn about the design of project workspaces from the above survey of workspaces in the Singapore Polytechnic. These are categorized as follows:

- Subliminal Messages
- Specialisation vs. workspace flexibility
- Space required and throughput vs. artefact size

Subliminal Messages

Project workspace can be designed to send subliminal messages to students using it. In the case of the IE/IDEA labs at T12601-T12606, the emphasis was to provide a vibrant, flexible and even “cool” workspace that students can identify with and enjoy using. The aim was to project a casual hobby club atmosphere where good, innovative ideas are welcomed. As such, vibrant colour schemes were used and modern equipment like wireless projectors and Smart boards were installed. Tables could be easily moved and reconfigured in different shapes to suit different learning activities. Various surveys of both staff and students have consistently shown that students enjoy using these labs.

In contrast, the MDC at W1112 is designed to be a formal workspace. It is used to conceive, design and fabricate industrial automation systems that meet industry specifications dictated by our industry partners. The layout and work environment in the MDC is hence deliberately designed to simulate what students are likely to find in the industry.

Specialisation vs. workspace flexibility

Depending on the type of projects built, specialised equipment may be necessary. When such equipment is required, the workspace loses its flexibility to be used in other ways. There is also less chance of the entire C-D-I-O process being housed in the same venue.

In the case of D&I Lab in T822, 2nd year students build an electronic project which has to be housed in a chassis. A dedicated workshop area in an adjoining lab equipped with drilling machines, metal cutters etc is available for students to do this. This workshop area cannot be flexibly used for other purposes. If the electronic portion of the project requires a microprocessor, then dedicated supporting equipment like emulator boards may be required. The bigger and bulkier these supporting equipment are, the less flexible the workspace becomes.

Another example is the requirement for machine tools in the Mechanical & Manufacturing Engineering School’s IE module. Machining in the Implement and Operate phase of the IE module is done in a dedicated machining workshop housed in the Project Lab in W1218. Because of the heavy investment in setting up the infrastructure, this lab is used for other modules requiring the same equipment as well. To free up the lab time, the Conceive and Design portion of the project is housed in another lab – at the IPC in W1113.

On the other extreme, students taking the School of EEE’s IE/IDEA module build simple electronic circuits and projects which involve mainly simulation, soldering and testing. The equipment required to run these projects are modest and portable. Students go to the equipment station and carry the equipment required to their work area and return them when they have finished. The artefacts that they build are also small in size. As such, the entire C-D-I-O process of these projects can be housed in the same place – at T12601 to T12606. Moreover, these workspaces are also flexible enough to be used for other purposes like conducting meetings, tutorials, lectures, seminars, school promotion activities etc.

Space required and throughput vs. artefact size

The amount of space and labs required for projects also depends on the size of the project artefact. Where project artefact size is large like in the case of Industrial Automation projects housed in the MDC in W1112, only a few projects can be housed in each multi-purpose assembly area at a time. This is because there has to be sufficient space to house the artefact-in-progress. If more than 1 team of students are doing similar projects, another venue has to be found for the second team even though the existing workspace may be free and is used for just storing the project. This problem can be mitigated somewhat if an effective storage system could be devised such that work in progress can be stored (perhaps in a vertical ASRS), freeing up the work area for other groups.

Where project artefacts are small, e.g. the ones built by School of EEE IE/IDEA or the D&I module students, each workspace can be timetabled for use repeatedly over the course of the week. In the case of T12601-T12606, a maximum of 8 4-hour sessions can be timetabled in each lab per week. Projects-in-progress can be simply taken home by the students or stored in relatively small storage spaces in the labs. The throughput of these labs is hence much higher.

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