CASE STUDIES OF INTEGRATING PROJECT BASED LEARNING INTO POLYTECHNIC ENGINEERING CURRICULUM

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ABSTRACT

Project-based learning provides opportunities for learners to apply knowledge and skills that they have learned to answer driving question(s) based on authentic problems or projects provided by the industry partners. Literature has shown that project-based learning develops learners to be better problem solvers and high-order thinkers, as well as improves learners' engagement. Hence, project-based learning has been adopted by School of Engineering (SEG), Nanyang Polytechnic (NYP), Singapore as one of the teaching methods to further improve the learner and teacher engagement, develop learners' critical core skills and close the learners' achievement gap. This paper details the journey of integrating project-based learning into the curriculum of three diplomas in SEG after a successful pilot study on adopting the Gold Standard project-based learning model provided by PBLWorks (Buck Institute for Education). Implementation in each diploma was uniquely designed to suit the curriculum and the needs of the learners. The modules adopting project-based learning teaching method required learners to apply knowledge and skills learned at different stages to answer driving question(s) based on authentic problems or projects provided by the industry partners. The effectiveness of project-based learning implementation was measured through the perceptions of the learners and feedback provided by both learners and lecturers. The learners showed interest in the projects and found them useful in developing the competencies necessary for the diploma. The paper will also share the challenges faced during the implementation and discuss the possible improvements that can be made to enhance future implementation.

KEYWORDS

Project-based Learning, Curriculum Design, CDIO Standard 7 Integrated Learning Experiences, CDIO Standard 8 Active Learning

INTRODUCTION

One of the main roles of engineers is to solve technical problems using their mathematical and science skills and competencies. Often, these problems will translate into projects of varied complexity. For the projects to be successful, future engineers should also be equipped with the necessary 21st century skills and be resourceful. Therefore, project-based learning is adopted by School of Engineering (SEG), Nanyang Polytechnic (NYP), Singapore, as one of the teaching methods, to equip learners with the necessary skills and competencies as future engineers. Studies have claimed that project-based learning provides several positive learning outcomes for learners, such as the development of problem solving and high order thinking skills (Pinho-Lopes & Macedo, 2014), better learning attitudes and “comparable or better” performance on content knowledge (Parker et al., 2011), and improved learner engagement (Almulla, 2020).

In SEG, from 2019 onwards, we contextualized and integrated the Gold Standard project design elements, teaching practices and lesson delivery phases developed by Buck Institute into the project modules, as well as the new techniques and tools that are developed for lecturers who are involved in delivering the project modules (Wong et al., 2022). After a successful pilot study in 2021, this paper describes the journey of integrating project-based learning into the curriculum of three diplomas in SEG, namely, Diploma in Nanotechnology & Material Sciences (DNMS), Diploma in Engineering with Business (DEB), and Diploma in Advanced & Digital Engineering (DADM). Implementation in each diploma largely followed the contextualized methodology described by Wong et al. but was uniquely designed to suit the curriculum and the needs of the learners.

METHODOLOGY

The three diplomas followed the four delivery phases, namely *Launch*, *Build*, *Develop* and *Present* phase (Larmer, Mergendoller & Boss, 2015, Wong et al., 2022) for their project-based learning implementation. It draws similarity with CDIO where Conceive, Design, Implement and Operate can be matched to the 4 delivery phases (Launch, Build, Develop, and Present) of project based learning Each phase consists of a whole suite of recommended activities to be done to achieve the desired outcomes. Figure 1 shows a typical thirty to ninety hours project module in SEG and how the project design elements, teaching practices and learning activities are integrated into a project-based learning module over a period of 15 weeks. Contextualization effort here would mean selecting an adequate amount of important and yet manageable activities to be carried out in each project lesson delivery phase to achieve the outcomes.

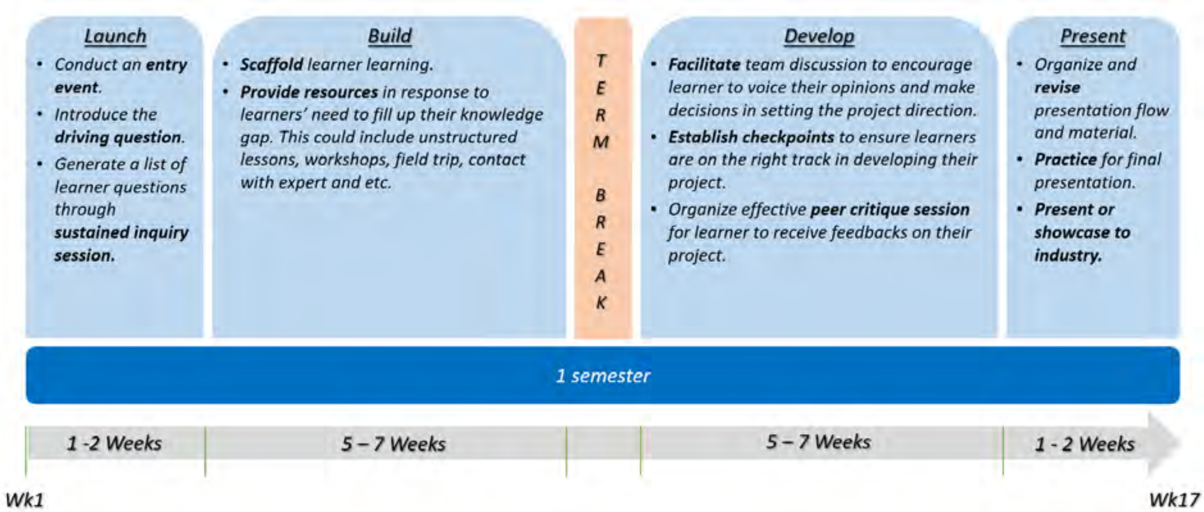


Figure 1: Project-based Learning Lesson Delivery Phases

For the Launch phase, entry event, introduction of driving questions and sustained inquiry session are the 3 activities to be carried out within the first 2 weeks for learners to get into the mood of starting their projects and to answer driving question(s) based on authentic problems or projects provided by the industry partners.

For the Build phase, a duration of five to seven weeks is recommended for learners to build up their knowledge and skills that are required for their projects. Structured or unstructured lesson can be conducted to scaffold learners learning. Activities such as field trip, workshop, talk by expert were recommended to be put in place as well.

After two weeks term break, the learners will proceed to the Develop phase to start developing their projects and a duration of five to seven weeks is recommended for learners to complete their project. In this phase, lecturers facilitate learners' team discussion, establish checkpoints to ensure learners are on the right track in developing their projects. An effective peer critique session should be organized for learners to receive feedback for their projects for further improvement or revision.

The last Present phase, learners are given one to two weeks to prepare and design their slides for their public presentation. Lecturers will review their slides and conduct practise sessions before the final presentation to the public.

IMPLEMENTATION

The project-based learning methodology was adopted by the three diplomas, for a total of three semesters from Year 2 Semester 1 to Year 3 Semester 1. The following subsections provide details on the implementation of each of the three diplomas following the four Project-based Learning Lesson Delivery Phases.

Diploma in Advanced & Digital Manufacturing (DADM)

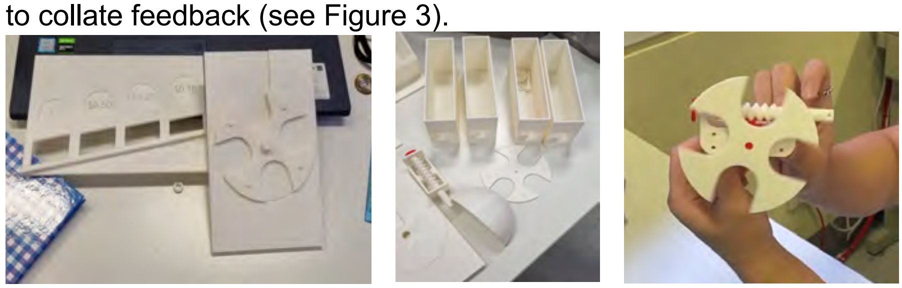
The curriculum of DADM was designed to prepare learners on precision engineering with Industry 4.0 and how it can be applied to every stage of product development – from design and creation, to tool and component manufacturing. The projects conducted in DADM were done progressively and sequentially in 3 modules, namely Integrated Development Project (IDP) 1, 2, and 3, with a possible progression to Internship or Final Year Project, which is done in the final semester of the course of study. Each of the module has a 60-hour class contact time.

(a) Integrated Development Project 1

Phase	Summary of activities
Launch	To interest the learners on their driving question, the learners were asked to solve a problem by playing a mini game. After the game, the driving question was provided to the students. Driving question was "How do we ensure precision in daily activities?". Project guidelines and limitations, such as (1) product must include at least 1 material from each of the following 3 groups: non-ferrous metal, ferrous metal, and polymers, (2) must include at least 2 mechanical elements and (3) using at least 3 different manufacturing methods.
Build	Topics such as Project Scheduling and Resource Management, and Advanced Manufacturing Technology (such as manufacturing of components using machining technology and numerical control in machining technology) were taught to equip learners with the necessary skills for the project.

Develop	The facilitator provides guidance to the learners to complete the deliverables needed, based on the guidelines and limitation provided in the Launch phase. This includes Low Fidelity Prototype, Project Initial Plan, Current Status of Project and Planned Status for IDP 2, and Logbook.
Present	The learners share their low fidelity prototype drawings to the facilitator and classmates to collate feedback (see Figure 2).  Figure 2: Examples of low fidelity prototype drawings

(b) Integrated Development Project 2

Phase	**Summary of activities**
Launch	The driving question on "How do we ensure precision in daily activities?" is revisited, and each team does a short presentation of their solution design from the previous module. The guidelines, limitations and deliverables were discussed.
Build	Topics such as Project Risk Management and Reporting, and Manufacturing of components using advanced machining technology were taught to equip learners with the necessary skills for the project.
Develop	The facilitator provides guidance to the learners to complete the deliverables which includes High Fidelity Prototype, Project Statue Report, Current Status of Project and Planned Status for IDP 3, Logbook and a Project File.
Present	The learners share their high-fidelity prototypes to the facilitator and classmates to collate feedback (see Figure 3).  Figure 3: High-fidelity Prototypes produced from IDP 2

(c) Integrated Development Project 3

Phase	**Summary of activities**
Launch	The driving question on "How do we ensure precision in daily activities?" is revisited, and each team did a recap on their project status in IDP 2. The guidelines, limitations and deliverables were discussed.
Build	Topics such as Introduction to Industry 4.0, Data Visualisation, UX for IoT, Marketing Survey and Project Pitching were taught to equip learners with the necessary skills for the project.

Develop	The facilitator provides guidance to the learners to complete the project with a working prototype incorporated with IoT.
Present	The deliverables include a poster and a working prototype (see Figure 4).  Figure 4: Example of a poster and a working prototype for IDP 3.

Diploma in Engineering with Business (DEB)

The curriculum of DEB was designed to merge the engineering and business disciplines, with the intention to equip the students with 21st Century skills to solve complex problems in the technically oriented business workplace. Under the project-based learning method, a series of three modules: Integrated Project – Ideation, Integrated Project – Realisation, and Integrated Project – Entrepreneurship, were developed and implemented as an essential part of the DEB curriculum. Each of the module has a 30-hour class contact time.

(a) Integrated Project – Ideation

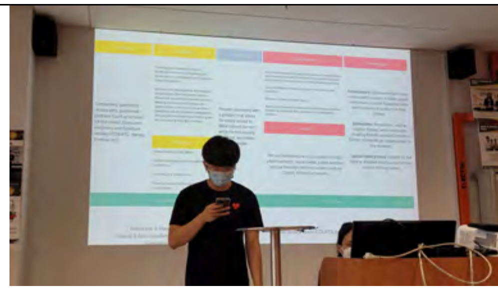
Phase	**Summary of activities**
Launch	The problem statements of the project are sourced from our industry partners or community collaborators, and they are presented to the students at the start of the module.
Build	To equip the students with the tools needed in developing solutions to the problem statements, human-centred design (HCD) approaches, which include Design Thinking, User Experience Design and Universal Design, are introduced.
Develop	Using the HCD approaches, the students are guided and facilitated to design and develop solutions to the problems. At this stage, they will create mock-ups or poster to explain their designs.
Present	During the final presentation, representatives from industry partners or collaborators are invited as members of the assessment panel. The learners present their solutions and receive feedbacks from the panel so that they can further improve their designs, as shown in Figure 5.  Figure 5: Learners presenting their solution design

(b) Integrated Project – Realisation

Phase	**Summary of activities**
Launch	The problem statements are revisited, and each team does a short presentation of their solution design from the previous module. The facilitator conducts a briefing on the tools and equipment available at the school's MakerSpace.
Build	The learners build their prototypes at the MakerSpace, as shown in Figure 6, through applying the knowledge and competencies in mechanical design, electronics and software attained from modules in the course.  Figure 6: Learners building their prototypes in the school's MakerSpace.
Develop	The facilitator guides the learners through an iterative process of testing, evaluation and refining of the prototypes.
Present	During the final presentation, whenever feasible, the representatives from industry partners or collaborators are again invited as members of the assessment panel. At this stage, some projects are identified to have potential to further develop into a full product and will be followed up as a 3-months long Final Year Project, which is part of the course curriculum.

(c) Integrated Project – Entrepreneurship

Phase	**Summary of activities**
Launch	At this stage, all teams are presumed to have a working prototype for their product. Each team does a short demonstration of their prototypes from the previous module. The facilitator presents to the students on the purpose of the module which is to develop a business model and write a business proposal based on their product.
Build	The facilitator presents the concept, principles, and process of setting up business as an entrepreneur. Tools like Business Model Canvas are introduced.
Develop	Using the knowledge and competencies they have acquired from the business-related modules in the course, together with the newly introduced tools, the students develop a complete business model of their product, which includes value proposition, customer segmentation, market analysis, cost analysis, etc. A business proposal is also drafted at this phase.
Present	During the final presentation, the assessment panel acts as potential investors, and the students pitch their business models and demonstrate their products.

	 Figure 7: Learner pitching their business model during the final presentation.

Diploma in Nanotechnology & Materials Science (DNMS)

The curriculum of DNMS was designed to equip learners with the necessary skillsets in meeting the emerging needs of materials and nanotechnology in various sectors. Like the other two diplomas, there were three modules identified to roll out project-based learning, namely Foundational Materials Science and Application, Polymers and Composites, and Materials Processing and Integration. Each of the module have a 90-hour class time, with at least 45 hours allocated for project. However, each project conducted in DNMS were independent of the other project. For each project, at least 2 technical core modules were designed to support technical knowledge required in the project.

(a) Foundational Materials Science and Application

Phase	Summary of activities
Launch	Entry event was organized at the beginning, with the industry collaborator invited to give a talk on the project. The driving question “How can we improve the corrosion resistance of steel products to reduce impact and save cost for industry?” was shared to the learners in the event.
Build	The facilitator equipped learners with the necessary knowledge in the field of steel products and provided guidance to learners in planning their experiment to address the driving question.
Develop	The facilitator provides research and testing support for students to investigate. The industrial collaborator provided samples for learners to experiment, test and characterize their results. Figure 8 shows an example of the steel sample and experiment setup, as well as learners in action during their experiments.  (i) (ii) (iii) Figure 8: (i) An example of the steel sample, (ii) example of an experiment setup, and (iii) learners in action during their experiments.
Present	The learners prepared a report to document the experiments done and the results. Also, the learners presented their findings and recommendations to the industry partners, facilitator, and their classmates.

(b) Polymers and Composites

Phase	Summary of activities
Launch	The collaborator was invited to give a talk on the project, to highlight the relevancy of their project to the industry application. The driving question “How can we develop an environmentally friendly composite for sound absorption application?” was introduced to the learners.
Build	Facilitator taught learners on composites, their properties and processing techniques. Learners were provided with budget to source for their own materials. The school provides the necessary lab facilities for materials processing, testing, and prototyping.
Develop	The instructor provided guidance and supervision through sustain enquiry activity and processing and testing equipment training. The collaborator provided expertise and advised to the students on the applications and implementation of the composites. An example of the composite produced by the learners, and the impedance tube to test the performance is as shown in Figure 9.  (i) (ii) Figure 9: (i) a composite sampled produced by learners and (ii) impedance tube.
Present	A public showcase was arranged, to allow learners to have an opportunity to share with industry partner their project work/learning and seek feedback to improve their work.

(c) Materials Processing and Application

Phase	Summary of activities
Launch	The collaborator was invited to give a talk on the project, to highlight the relevancy of their project to the industry application. The driving question “How can we develop alternative applications of the Acrylic Polycake industrial waste materials to contributes towards sustainability and economic benefits?” was introduced to the learners and they are able to clarify their doubts directly with the collaborator during the talk.
Build	The facilitator explored on the waste materials composition with the learners. The processing and testing methods were introduced. The facilitator guided the learners to plan their project schedule.
Develop	The collaborator provided the industrial acrylic polycake waste while the facilitator provided consumables, as well as lab facilities for materials processing, testing, and prototyping. Collaborator provided mentorship to the learners while the facilitator provided guidance through sustain enquiry activity and process and testing equipment training.
Present	The learners presented their prototypes and project finding to the collaborator and facilitator at the end of the project. Some of their prototypes can be seen in Figure 10.

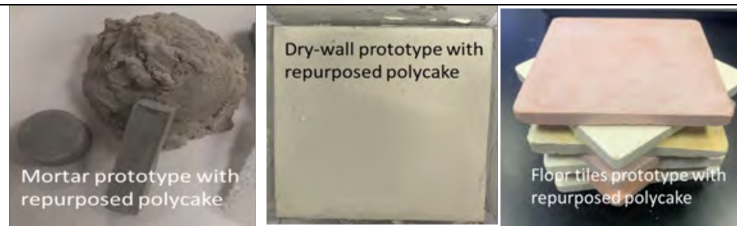


Figure 10: Prototypes produced at the end of the project

EVALUATION METHODS

To evaluate the effectiveness of the project-based learning method to our learners, 2 methods were used. The MUSIC Model of Motivation (Jones, 2009 & 2018) was adopted as part of the survey instrument to measure the impact of project-based learning on learners' motivation in five dimensions, namely empowerment, usefulness, success, interest and caring. An additional dimension on soft skill is added into the survey instrument (Wong et al., 2022). From the response to the questionnaires, a score was obtained for each scale, by calculating the average of the values for the questions in the scales, as recommended by Jones (2018) in the MUSIC Model of Motivation. This evaluation method was adopted by DADM and DNMS.

The other evaluation method was a combination of a survey with 18 statements and a focus group discussion (FGD). The survey's statements adopted the 3M – Meaningful, Motivational and Memorable (Bretz, 2001, Harackiewicz et al., 2002, Zubairu, 2016) to understand the learners experiences. The survey questions together with the classification of their categories, and the related learning experience using 3M can be seen in Appendix I. From the survey results, four statements with the lowest response scores were identified and used as discussion points in FGD. The FGD involved 8 learners from different levels and classes and were facilitated by 3 facilitators. This method was used to evaluate the DEB projects.

FINDINGS AND DISCUSSION

Adaptation from MUSIC Model of Motivation

The survey was rolled out to the DADM and DNMS learners at the end of the module. The learners were encouraged to respond to the survey; however, it was kept optional to receive genuine responses. All responses were tabulated, and a score was obtained for each scale, by calculating the average of the values for the questions in the scales, as recommended by Jones (2018) in the MUSIC Model of Motivation. The results were placed in a bar chart and was compared with the target score of 5.0, while the maximum score is 6.0. An example of the results for a module is shown in Figure 11.

In the survey, learners can also provide written feedback to the facilitators. With the scores and learners' feedback, the team discussed with the module leaders on possible contributing factors for lower scoring and areas for improvement.

The results from the surveys done across the modules found that learners felt cared for (caring) as facilitators do their best to scaffold the learning, and they were given ample of opportunities to practice their soft skills (soft skills). Learners also felt empowered (empowerment) as they were given autonomy to design their prototypes or experiments within the guidelines given.

Learners were interested in the project (interest) and found the project to be useful for their learning (usefulness), so long as they saw relevancy in the project.

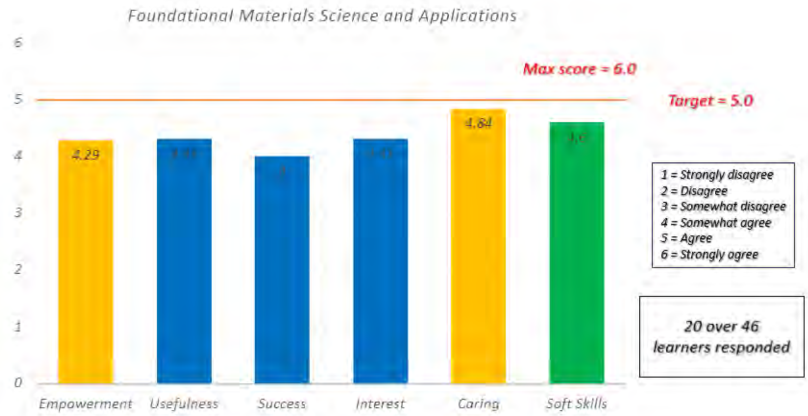


Figure 11: Results from the MUSIC Model of Motivation survey for DNMS's Foundational Materials Science and Application module

However, learners felt less confident in their abilities to complete their projects (success). Learners cited insufficient preparatory lesson and resources to prepare them for the project, and at times, unclear module delivery, project and assessment components that were communicated to them. For improvement, module leaders will work on better communications to the learners on the intent, limitation, and assessment components of the project. Module leaders were also encouraged to conduct peer evaluation periodically, as some learners shared unhappiness in workload among teammates, which could undermine their success in completing the project and scoring a good grade. Peer evaluation will be able to assist facilitator in mediating the issue quickly.

3M Survey with FGD

The 3M survey in Appendix 1 was rolled out to the DEB learners at the end of the module. All responses were tabulated, and a score was obtained for each statement category. A Likert scale of 10 was used, with a score of 1 given for strongly disagree while a score of 10 for strongly agree. Table 1 shows the mean score received.

Statement Category		Mean score
1	Team Dynamics	8.04
2	Self-fulfilment	7.50
3	Applicability	7.48
4	Skills	7.38
5	Assessments	7.08

Table 1: Mean score for each Statement Category for the 3M Survey with DEB learners

All five categories (Team Dynamics, Self-fulfilment, Applicability, Skills, and Assessments) have a high score of higher than 7.0. The high scores of the responses provided a reassurance to the facilitators that the delivery of the modules was in a good shape. It also showed that, in general, the learners were motivated, they found the modules meaningful, and their experiences in attending the modules were memorable.

Team Dynamics has the highest score, and Assessments has the lowest. The learners' experiences were very much influenced by their relationships with teammates. With a high score in Team Dynamics, we are confident that the current management of the team dynamics during the lessons is effective. The low score in the category of Assessments reflected the frustrations some learners have where they feedback that the effort that they must put in is too much for a 30-hour module.

Four questions with the lowest scores were further discussed in depth in FGD. Some insights into important operational issues were gained from the learners' perspective. First, a peer assessment is recommended to avoid the perception of unfairness where some team members put in less effort than others and the facilitator is unaware of it. Second, there were too many different microcontroller platforms available as choice and the learners find it confusing when developing the prototype. It is recommended to standardize on one microcontroller platform. Lastly, there were too many assessment tasks in the modules and hence a review of the number of assessment tasks is recommended.

CONCLUSION AND REFLECTION

Three diplomas in SEG have successfully implemented project-based learning with the four delivery phases, namely *Launch*, *Build*, *Develop* and *Present* phase. Even though there were slight variations among the implementations, similar findings were observed between both surveys. The learners were interested in the projects and found them useful in developing the competencies necessary for the course. Across all projects, the learners' confidence score in completing their projects seem lower, and assessments are often a main concern for the learners as this concerns their grades. This would require an in-depth study to explore how and why project-based learning appears not able to increase learners' confidence in completing the project.

With the successful roll out of project-based learning in these diplomas and the relevancy to the learners, the team is looking into assisting more diplomas to adopt the method. The team will also plan to provide more structured training to support module leaders in integrating project-based learning into the project modules, as well as equipping them with the facilitation skills which are essentials in delivering project-based learning lessons.

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APPENDIX I

S/No	Survey items about your experience in attending Integrated Project (IP) modules: After attending Integrated Project modules, I …	Category	Meaningful Motivational Memorable
1	feel closer to my teammates than before.	Team Dynamics	Mem, Mot
2	am satisfied with the way teams were formed.		Mot
3	become a better team player than before.		Mot, Mean
4	find it enjoyable to work on the projects with my teammates.		Mem, Mot
5	have gained skills in handling machines and equipment when making the prototypes.	Skills	Mot
6	have gained skills in programming and using CAD software.		Mot
7	am confident to apply the skills (both in hardware and software) I acquired in the future.		Mot, Mean
8	find it enjoyable to learn how to use new machines and equipment.		Mot, Mem
9	think the number of assessments in the module is appropriate.	Assessments	Mot
10	think the modes of assessments (presentation, report writing, making prototypes, etc.) are appropriate.		Mot
11	think the preparation time for each assessment is sufficient.		Mot
12	have a good understanding of the process of product development.	Applicability	Mot, Mean
13	feel more confident to handle technical tasks in the future.		Mot, Mean
14	feel more confident to draft a business plan for a good idea in the future.		Mot, Mean
15	find it satisfying to push myself beyond my comfort zone when doing the project.	Self-fulfilment	Mot, Mem

16	find it satisfying to see my idea turns into a design and finally to a working prototype.		Mot, Mem
17	am able to apply the knowledge and skills learnt from other modules on the project.		Mot, Mean
18	feel that the modules are enjoyable.		Mem
19	this is a control question, please choose number four.	Control Statement	N.A.

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