ACTIVE LEARNING THROUGH 3D PRINTING TECHNOLOGY AND PROTOTYPING

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ABSTRACT

This paper describes our journey in using 3D printers as a pedagogical tool to implement active learning (CDIO Standard 8) in the Biomedical Project module in the School of Engineering at Nanyang Polytechnic, Singapore.

The Biomedical Project module aims to develop students' skills in designing an innovative biomedical product with business ideas to market and package it for commercial consumption. By incorporating 3D printing into the module, students are involved in an iterative and connected process that empowers them to be better able to experiment with their innovative design concepts and test their designs for fit and function. It exposes students to various facets of engineering and design disciplines, as well as promoting creative thinking among the students.

Besides the strategies used in designing and implementing the learning activities with 3D printing, our experiences in incorporating other active learning strategies in the module, like flipped classroom in lecture lessons and mini-seminar for students to pitch their business ideas, are also highlighted in the paper.

This paper ends with a discussion on the outcomes of the active learning strategies used in the module by examining students' interest in learning biomedical technologies/concepts and their perception towards this active learning approach.

KEYWORDS
Active Learning, 3D Printing, Prototyping, Biomedical Product Design, CDIO Standard 8.

Note – In the context of Nanyang Polytechnic, the term 'course' refers to a 'program' while the term 'module' refers to a 'course'. For example, *Diploma in Biomedical Engineering* is a course; *Biomedical Project* is a module.

BACKGROUND

Introduction
Polytechnic education in Singapore aims to provide industry relevant education and training for the workplace, to give Singapore a competitive edge as we move to a knowledge-based economy [1]. At Nanyang Polytechnic (NYP), we strive to provide our students with a learning and development experience that nurtures their potentials and helps them develop specific attributes to excel in work, life and learning. The education equips them to thrive in rapid economic and social changes, and contribute to Singapore's technological, economic and social development. In meeting these goals, our graduates must possess critical & transferrable skills and desirable personal values. As our graduate attributes spell out, we would like our graduate to be:

- ✓ Professional Competent – The graduate is knowledgeable and skilled in his field of study so as to apply them effectively in workplace. The graduate possesses multi-disciplinary perspectives, and has the passion for lifelong learning.
- ✓ Competent in 21st Century Skills – The graduate is ready to sustain personal and

professional development. The graduate has essential skills in civic literacy, global awareness & cross-cultural understanding; critical & inventive thinking; and information literacy, communication & collaboration.

- ✓ Innovative & Enterprising – The graduate thinks critically and is ready to recognise challenges and embrace them as opportunities. The graduate is able to generate creative ideas, exploit resources and develop practical approaches to create innovative solutions.
- ✓ Socially Responsible – The graduate recognises and upholds personal and professional ethics. The graduate is able to appreciate and respect cultural and intellectual diversities and is caring and compassionate to the community.

These graduate attributes are translated to the student learning outcomes and course educational objectives for the courses offered by the School of Engineering (SEG) at NYP, which define what our graduates are able to perform upon graduation as well as a few years after graduation, respectively.

In 2013, the SEG conducted a major course evaluation and review for the Diploma in Biomedical Engineering (DBE). The course review evaluated how the course educational objectives and student learning outcomes were able to meet the current needs of various stakeholders, including potential employers from industry and government agencies, our alumni and faculty members of SEG. There are many enhancements to the curriculum from the review, one of them was to deepen the adoption of the Active Learning (CDIO Standard 8) pedagogical approach with the objectives to further improve our engineering education, and to better prepare our graduates to be more capable of carrying out self-directed learning, problem-solving and collaborative team work. In this paper, we present in detail one of these selected modules, the Biomedical Project module, as a reference model for the implementation of active learning in the DBE course.

Challenges in Existing Practice

Before the course review, students in the Biomedical Project module would go through the processes of ideation, designing and prototyping. Typically a few problems related to healthcare and medical device were given to the students and they would form teams of two to three members to look into solving the problem with innovative solutions. They would usually come out with two to three ideas or designs and build prototypes using recyclable materials. Sometimes it was a mere paper exercise where students shared their ideas through poster presentation. This was due mainly to the time-consuming processes that students had to go through if they were to fabricate a slightly more complex prototype, given that the module was a 60-hour module. The limitations of such an approach were obvious in that the students were not able to recognize and experience the true challenges in making biomedical products. They were also not able to appreciate the process in building and testing the functionality of the products if the prototypes were not constructed fully, and hence affecting their assessment outcomes. In the CDIO terms, students experienced the ‘Conceiving’ and ‘Designing’ aspects of the product lifecycle, and partially on ‘Implementing’ and lacking on ‘Operating’, which are important aspects of the engineering education. It is through the ‘Operating’ phase that the students were able to perform the product trial, solicit feedbacks from end users, and iterate the designs to better meet their needs. Due to these constraints, students’ feedbacks were not as good as we hoped to achieve at the end of the module delivery.

Active Learning Pedagogical Approach

Since the course review, the DBE has implemented the Contextual Teaching and Learning (CTL) pedagogical approach [2] in a number of selected modules. The CTL pedagogy, which is also the approach adopted by other courses offered by SEG at NYP, encourages faculty members to relate subject content to real world situations / context and to motivate students to connect acquired knowledge to applications in real life.

In order for CTL to be deployed effectively, we have decided to exploit the additive manufacturing technology through the rapid prototyping approach. Additive manufacturing is defined as the process of joining materials to make objects from 3D model data, usually layer upon layer [3]. Rapid prototyping is one form of additive manufacturing and it is commonly used in making engineering prototypes. 3D printing is the process of fabricating objects through the deposition of a material using a print head, a nozzle, or another printer technology in the rapid prototyping process. Institutions exploiting 3D printing technology found that it could enhance students' practice of visual spatial skills to perceive and visualize significantly more complex objects [4]. 3D printing also allows the institutions to adopt the techniques of rapid prototyping engineering and fundamentals of engineering service processes in the curriculum [5].

More importantly, by incorporating 3D printing into the 'Implementing' and 'Operating' aspects of the product lifecycle, students will be involved in an iterative and connected process that empowers them to be better able to experiment with their innovative design concepts and test their designs for fit and functionality. It exposes students to various facets of engineering and design disciplines, as well as promoting creative thinking among the students.

METHODOLOGY

Strategy

To achieve CDIO active learning experiences and outcomes for this Biomedical Project module, the strategy focuses on incorporating active learning pedagogy for imparting product development and the technopreneurship skills sets. Students are expected to complete an assignment with special emphasis on biomedical engineering-related applications.

Figure 1: Product Development Cycle

Using the typical Product Development Cycle as shown in Figure 1, students will research on project engineering including emphasis on information gathering, usability, robustness of design, costing analysis, business entity and structure, business plan and its various components, and intellectual property protection. The focus is on applying the technopreneurship skills to the creation process for biomedical engineering-related applications. At the end of the module, each team of students complete a business plan to market the designed and constructed 3D printed innovative prototype.

Defining the Module Learning Outcomes

The constructive aligned curriculum mentioned in the CDIO syllabus [6] was adopted in defining the module learning outcomes. The module learning outcomes stated in the module syllabus are constructed with student learning in mind and they are consistent with and aligned to the student learning outcomes and course educational objectives articulated at the course level.

Thus, the student learning outcomes for this module are defined as follows:

The students will be able to

- *develop a business plan*
- *design an innovative product*
- *identify and analyse design constraints associated with the product*
- *interact and collaborate with others in teams to complete the design of an innovative product*

Designing Learning Activities

The learning activities are designed for students to achieve the module learning outcomes. These activities are typically carried out in the form of lecture, tutorial and practical sessions. Table 1 shows the chapter 1 to 3 of this module, as an example of the plan. The cognitive skills levels that the student would attain in these activities are classified into four levels, namely Remembering (I), Understanding (II), Applying (III), and Analysing/Evaluating/ Creating (IV).

In the instructional outcomes, the module is designed with 15 hours of lecture and 45 hours of practical. Chapter 1 and 2 are allotted only for lecture as they are intended for students to be introduced to the technopreneurship and business ownership. However, chapter 3 is allotted with the entire 45 practical hours as it is the main focus of product development cycle, in which each group of students is to deliver an innovative product by the end of the module. The CDIO approach is applied to provide integrated, active and collaborative learning with the aims to develop skills in problem formulation, estimation, modelling and solution. To make more effective and efficient use of student learning time in acquisition of disciplinary knowledge concurrently with personal and interpersonal skills, and product, process, and system building skills [6], we also incorporate other active learning strategies in the module, including flipped classroom in lecture lessons and a mini-seminar at the end of the semester for students to pitch their business ideas and products.

Table 1: An excerpt of Instructional Outcomes (L-Lecture, T-Tutorial, and P-Practical)

No	**Topics**	**Instructional Outcomes** At the end of this topic, students will be able to:	**L**	**T**	**P**	**Cognitive Skills Level***
1.0	**Introduction to Biomedical Project and Technopreneurship**		1	0	0	
1.1	Introduction to the module	• describe the objectives of the module • locate the linkage of this module to other modules in DBE course • state the relevance of this module to the industry				I
1.2	Introduction to Technopreneurship	• recognize the role of entrepreneurship in Singapore • assess one's suitability for entrepreneurship				III
2.0	**Business Ownership**		4	0	0	
2.1	Forms of business ownership	• identify different ways to start a company • identify different types of business ownership				II
2.2	Registering your business	• select an appropriate company name • write a mission statement • prepare company objectives				III
2.3	Marketing research	• identify targeted market				II
2.4	Feasibility study	• develop a SWOT analysis on one's business • prepare a feasibility study for one's business venture				III
3.0	**Product Development**		3	0	45	
3.1	Business product	• identify the product life cycle • recognize the importance of intellect property • recognize the importance of inventory management				II

No	Topics	Instructional Outcomes At the end of this topic, students will be able to:	L	T	P	Cognitive Skills Level*
		• develop a healthcare prototype				IV
3.2	Marketing plan	• examine marketing mix • recognize the need for advertising & promotion				II

Assessing Student Learning

When planning the module learning outcomes, assessments and learning activities, we use the CDIO Syllabus v2.0 as a guide for defining the skills. Table 2 shows the criteria for assessing students' business plans and prototypes, and Table 3 shows the relation of our work on module learning outcomes, assessments and learning activities with the CDIO Syllabus v2.0.

Table 2: Assessment Criteria for (a) Business Plan and (b) Prototype

(a)

Category	Scoring Criteria	Score
Format	Business plan is prepared using appropriate format specified and details duly completed	10
Content	Each topic is duly completed with appropriate and suitable content	60
Professionally Done	Professional looking and accurate representation of the data in tables, graphs, and written form; graphs and tables are appropriately labeled and titled	20
	All appendices are properly referenced, labelled and appended at the end of the report	10
	Total	100

(b)

Category	Scoring Criteria	Score
Poster Information	Indicate name of invention, pictures of referenced product, indicate 2 extra features in the product, names of inventors	5
Poster Design	Engaging, visually simulating, aesthetically appealing use of colour, diagrams and text	10
Prototype	Complete Prototype	10
	Functionality	25
	Uniqueness	10
	Prototype is professionally done	20
	CAD model is professionally done	20
	Total	100

Table 3: Mapping CDIO Syllabus to the components used in the Constructive Aligned Curriculum based on Extended Syllabus v2.0.

	CDIO Syllabus v 2.0*															
	1.1	1.2	1.3	2.1	2.3	2.4	2.5	3.1	3.2	4.1	4.2	4.3	4.4	4.5	4.6	4.8
Module Learning Outcomes	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Assessment	●	●	●	●	●	●		●	●		●	●	●	●	●	●
Learning Activities	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

* Topics in Extended CDIO Syllabus version 2.0 are mapped as follows:

1.1 Knowledge of Underlying Mathematics and Sciences (mapped to 1.1.1, 1.1.2 & 1.1.4)
1.2 Core Engineering Fundamental Knowledge
1.3 Advanced Engineering Fundamental Knowledge, Methods and Tools

2.1 Analytic Reasoning and Problem Solving (mapped to 2.1.1 - 2.1.5)
2.3 System Thinking (mapped to 2.3.1 - 2.3.4)
2.4 Attitudes, Thought and Learning (mapped to 2.4.1 – 2.4.7)
2.5 Ethics, Equity and Other Responsibilities (mapped to 2.5.1)
3.1 Teamwork (mapped to 3.1.1 - 3.1.5)
3.2 Communications (mapped to 3.2.1 – 3.2.10)
4.1 External, Societal and Environmental Context (mapped to 4.1.1 & 4.1.2)
4.2 Enterprise and Business Context (mapped to 4.2.3, 4.2.4 & 4.2.7)
4.3 Conceiving, Systems Engineering and Management (mapped to 4.3.1, 4.3.2 & 4.3.3)
4.4 Designing (mapped to 4.4.1 – 4.4.6)
4.5 Implementing (mapped to 4.5.1 – 4.5.6)
4.6 Operating (mapped to 4.6.1, 4.6.2, 4.6.4 & 4.6.6)
4.8 Engineering Entrepreneurship (mapped to 4.8.1, 4.8.2, 4.8.3, 4.8.4, 4.8.7, 4.8.8)

Delivering of Lesson

The expected deliverables of this module are students' biomedical prototypes and their business plans. To facilitate the students in achieving these outcomes, the class is organised into teams of two to three members. The teams are to plan and organise themselves for the tasks assigned. As time is an important element in the completion of the assigned tasks, lecturers need to manage the 60 hours that are spread over 15 instructional weeks (four hours per week) for best student learning experience. Based on past experiences, instead of planning one hour of lecture lesson and three hours of practical lesson every week, it is more effective to arrange these four hours of lessons in the following manner on alternate week basis over a duration of 14 weeks: two hours of lecture and two hours of practical lessons on one week, and four hours of practical lessons on another week. During the last instructional week, the four hours are combined for students to prepare and participate in the mini-seminar. The two-hour lecture session is conducted using flipped classroom approach, where students read materials provided off-campus and spend face-to-face time in-campus focusing on project discussion and construction of the biomedical prototype, and strategizing their business plans with team members. The delivery plan is shown in Table 4.

Table 4: Plan for Delivery of Learning Activities

Learning Activities	Title of Learning Activities	Lecture (Flipped Classroom)	Practical
1	Are you an entrepreneur?		√
2	Designing my techno-product	√	√
3	Get started		√
4	Know your environment	√	
5	Sizing your competitor	√	
6	Know your customer	√	
7	Financial planning	√	
8	Understanding advertisement	√	
9	Making your product known	√	
10	Financial management	√	
11	Business plan (I)	√	
12	Business plan (II)	√	

Implementation

This module requires the students to work in teams. Before each lesson, individual student is required to access the learning management system to read the module materials. The face-to-face classroom sessions consist of group discussion, presentation, and working on product ideas. The lecturer, acting as a facilitator, guides them in classroom activities and provides technical consultation on product designs. The implementation of flipped classroom and practical sessions require the students to organize their time based on the scheduled sessions.

As a team, the students need to organize themselves in carrying out their tasks as assigned and planned. Submission of progress report is monitored and the dates when the reports are received are published to the learning management system. Lecturer provides timely feedback to the students on their work submitted, allowing them to make improvements to their works.

For instance, as part of learning activity 5, the teams discuss their products' strengths and weaknesses as compared to competitors' products. Based on the findings, they review their designs to improve their products' strengths. As the students progress on their design, the lecturer monitors and participates in their design evaluation and review process. The lecturer shares his or her experiences and provides insights to various design methodologies. Once the designs are ready, the students construct their prototypes using 3D printer.

From the 3D printed prototypes, lecturer shares techniques involved in evaluating the 3D printed products, and the students review and evaluate the fit and functionality of the products. Often students are able to identify mistakes made during the design stage and make changes to their design to rectify them. The benefits of this iterative approach are many folds. First, students are able to find the right context and connection between the knowledge acquired in the module and the products that are being 3D printed. Second, students are able to acquire higher order thinking skills when they are evaluating and testing the prototypes. Third, students are more confident in marketing their works as they are able to complete a functioning prototype.

Finally, to showcase the effort of the students, a student mini-seminar is organized. The platform allows the students to 'sell' their ideas and the developed products (see Figures 2 & 3 for pictures taken at the mini-seminar). In this mini-seminar, the teams have 10 minutes to present their developed products to a panel of assessors. Following the presentation, an exhibition is organized for the teams to display their posters, business plans and developed products as well as to provide opportunity for the teams to hone their skills in seeking 'seed money' from the assessors who act as 'potential investors'.

Figure 2: Student sharing his biomedical product with a 'potential investor'

Figure 3: Students with their posters and 3D printed product

RESULTS AND DISCUSSION

Measure

To measure the effectiveness of this active learning through 3D printing approach, data was collected from an experimental group of 48 students who were enrolled in the Biomedical Project module in semester 1 of academic year 2015. First, we examined students' academic performance in this module which was mainly contributed by their ability to realize a physical and functional prototype, together with a sound business plan. Second, we examined the data collected from the end-of-semester module feedback where students provided feedback on all modules they attended in a semester, covering module content, delivery and learning environment. Finally, we examined the data collected from a survey that was specifically administered to this group of students to gauge the feasibility and effectiveness of the implementation and acceptance of the approach by students. The results are reported in the following sections.

Academic Performance

Previously, without the availability of 3D printing technology, students were unable to grasp the fit and functionality of their designs. In addition, students who conceptualized products with more complex designs were not able to produce the prototype due to time and cost constraints. Thus these students received lower scores as they were not able to demonstrate a complete product. With the availability of 3D printers, students were able to visualize and validate their designs, and make the necessary adjustments to rectify any shortcoming before producing the final prototype. It was through this iterative process that most of the students were able to demonstrate a complete and functional prototype, leading to overall improved module grades performance as shown in Figure 4.

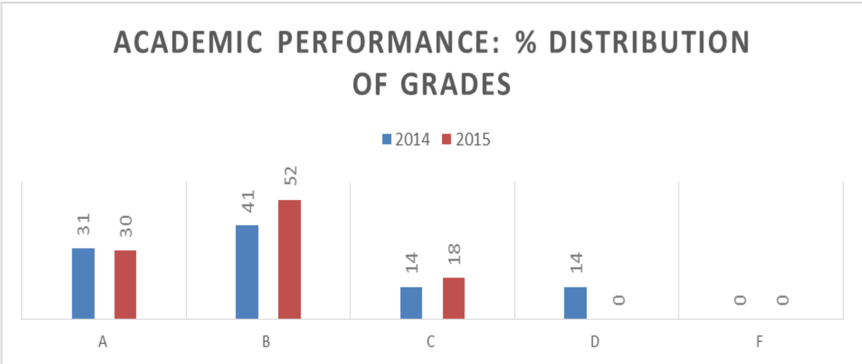

Figure 4: Comparison of students' academic performance in Biomedical Project module

In addition, based on the analysis of the submissions of the prototypes, all teams were able to avail their prototypes for assessment. Out of 20 teams, 85% of the teams submitted completed prototypes. In terms of functionality, points awarded range from 10-25 points with an average of 18.5 points. About 70% of the teams were able to score a median of 20 points for functionality. This good score reflected on the achievement for functionality as compared to about 55% of the 20 teams scoring a median of 20 points for 2014.

Student Module Feedback

There was also improvement in the module feedback provided by the students at the end of the semester for the Biomedical Project module, especially when students were asked to rate items related to the organisation and adequacy of the module. The ratings of 'Agree' and 'Strongly Agree' showed an increase of about 10 percentage points, from 85% in 2014 to 95.5% in 2015. These items included the clarity of module learning outcomes, the design and organization of module materials, the availability and quality of facilities and equipment, the e-learning components and the grading criteria. This improvement indicated a good acceptance of the active learning through 3D printing approach by the students when the approach was implemented in the module.

Surveys

Through surveys, students perceived that the flipped classroom pedagogical approach gave them an opportunity to learn in a dynamic and interactive environment. Module materials and video-recorded lectures were viewed by students before the face-to-face session in the classroom. Time in the face-to-face session was devoted to project, presentation or discussion which allowed students to have more time to interact and collaborate with their team members leading to better learning experience and teamwork spirit for the students. The survey results are shown in Figure 5.

A good 83.7% of the students responded strongly to better learning experience from flipped classroom as opposed to the traditional lecture. 86.1% of the students preferred group collaborative activities. This implied that the students had a keen interest in working in teams.

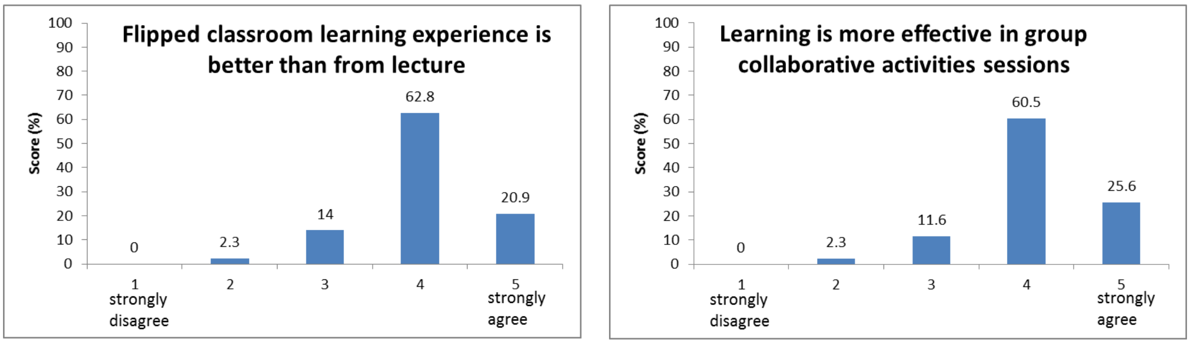

Figure 5: Results of a survey carried out after the new implementation.

CONCLUSION AND REFLECTION

The main outcome of the Biomedical Project module is for students to be able to produce an innovative, functional biomedical product with a good business plan. The successful development of these products and plans required active participation of the students. To facilitate the learning process, active learning environment needs to be created for students to participate actively in a collaborative manner within a team. The higher level of active participation from students in the experimental group was seen from the completion of their final prototypes and business plans.

It is important to ensure ownership is given to student on the development of the biomedical product. By changing lecturer's role to facilitator using the flipped classroom approach, students in the experimental group were responsible for their learning and the deliverables. It encouraged students to explore and discuss among themselves to find the best solution, with the lecturer providing the necessary facilitation.

With the use of 3D printing technology for rapid prototyping, the realisation of more complex biomedical products become achievable within the time given in the Biomedical Project module. In fact, many students in the experimental group were able to iterate their designs for more than two times to address shortcomings in their products. Through this process the students gained valuable experience in translating digital models into actual functional physical parts which they would not have if they were not able to build the complete prototypes. The students also learnt that features that they created in digital models might not be translated successfully into a functional prototype due to issues such as space, assembly, materials, and many others that they discovered in this process.

The student mini-seminar, on the other hand, provides the students an avenue to market their ideas and products. The presence of 'potential investors' at the exhibition created an exciting and real-life environment for the students in the experimental group to showcase and sell their products. The environment also required the students to be creative in using various media to promote their products and be able to respond to queries quickly and confidently. Under such situation, the students needed to demonstrate their ability to think and respond on their feet.

We conclude that the active learning using 3D printing approach undertaken by this module improves the students' learning experiences and increases their knowledge and skills in building and marketing their biomedical products. The use of 3D printing technology enhances the complexity level of the projects that students can work on. The students have also acquired employable and transferrable skills which are specified in our graduate attributes. The challenges faced are the availability of the 3D printers as well the space for development work outside students' scheduled lessons.

To further encourage active learning (CDIO Standard 8), we plan to build a maker space equipped with 3D printers, CAD tools and workstations for students to use them anytime outside their scheduled lessons. This facility will provide students with more opportunity to develop their innovative and enterprising spirits, to enhance students' skills in design and development works, to create more prototypes which could be used as project references and inspirations in the workplace, and to be future-ready.

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BIOGRAPHICAL INFORMATION

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