Innovative engineering project from engineering design to implementation-base on CDIO model

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ABSTRACT

In the past, the higher education in Taiwan aimed to create elites in the field of engineering. However, the conventional subjects and curriculum taught were mainly focusing on the introduction and understanding of theories. So students who only accept professional theories, the technology developed is not necessarily the needs of the industry, hence affecting the competitiveness of the country. The importance of "Creative Education" was mentioned in many research papers around the world when discussing how to enhance national competitiveness. Feng Chia University is devoted to promote "The Project of Innovative Engineering". By borrowing the experience of innovative education from Purdue University and combining it with the CDIO model, Feng Chia University created a systematic process for the project of innovative engineering. This allows students to discover and define problems, analyze and simulate actual situations, conceive and invent products, and in the end, achieve product evaluation and innovation development.

This paper introduces the procedure of how Feng Chia University integrated the CDIO framework into innovative education, and how, they through curriculum development, encourages students to engage in active learning and gather learning experiences rather than passive note-taking. The results of the current two semesters have shown that by transforming industrial design into a project of innovative engineering really does enhance students' motivation for active learning. The learning goal and process created based on Bloom's taxonomy is set to start with "creativity". Under this guideline, students are willing to learn the contents related to "analysis", "assessment" and "application" more actively, leading to an outcome of the enhanced ability to "memorize" and "comprehend". Moreover, by using the CDIO framework to create the project of innovative engineering, it allows teachers to overcome

the time limitations which existed in the system before, and at the same time enhances the depth of learning for the students significantly.

KEYWORDS

Practical skills development, Project-based learning, Self-determination theory, Bloom's taxonomy, Standards: 1, 2, 3, 4, 7, 8.

INTRODUCTION

Now a day, international competition is still increasing, which most of the medium and large enterprise keep expanding or maintaining their global market share aggressively. On the other side, the sense of internationalization is now a very popular concept for the younger generation in Taiwan, and also many developed countries in Asia. For the higher salary and better social welfare, to study or be employed abroad in Europe, North America or Australia are one of the important milestones in their life planning. How to cultivate student with certain international competitiveness during the higher education is the topic that university attaches great importance to.

Generally, higher education in university is the last step of professional knowledge and ability development before students entering the society in Taiwan, which the net enrollment rate of higher education is about 73 % in age 20 in 2017 (Educational statistics, 2017). Therefore, University is playing a very important role in connecting 12-year basic education and employment successfully.

From the report of the National Association of Colleges and Employers (NACE) published in November 2018 (NACE Job Outlook 2019, 2018), the survey results of attributes employers seek on a candidate's resume indicate that the top 5 attributes are communication skills, problem-solving skills, ability to work in a team, initiative, and analytical/quantitative skills. On the other side, about the career readiness competencies, critical thinking/problem solving, teamwork/collaboration and professionalism/work ethic are the top three of the weighted average rating, which is 4.66, 4.48 and 4.41, respectively under a 5-point scale. From the above report, employers attach much importance to the soft skills/ability of candidates. However, during the 12- year basic education in Taiwan, most of our students are educated to pay attention to memory knowledge only. In most of the cases, the score of examinations is the only key performance indicator of student learning effectiveness. Many of Taiwanese students lacked practical experience, and become disjointed with the real world requirement of human resource because of the monotonous and rigid teaching strategy.

The main causes of this problem are the way of classroom management. In Taiwan, Learning environment are usually created as a very traditional teacher-centered classroom. In the teacher-centered learning environment (Emaliana, I. (2017), Garrett, T. (2008)), the teacher is the sole leader who plays important roles in the learning process and evaluation. On the other hand, students are viewed as learners who receive knowledge passively with the "right answers" only. Under the monotonous teaching strategy with "one answer questions", it is easy to cause our students to lose the ability of judgment/critical thinking. The low motivation for learning is also easily become the by-product of this kind of learning environment.

To avoid the same problem that continues to occur, this paper aims to build up a new hybrid teaching strategy which including both the teacher-centered and student-centered learning environment with the idea of CDIO process. The strategy was designed from the idea of innovative education of Purdue University, who pay more attention to the balance between soft skills and professional knowledge, and is redesigned with a combination of CDIO structure as a new teaching strategy for FCU students. The module “Innovation project - foundation” is implemented for first-year university students in the International school of technology and management, Feng Chia University.

COURSE DESCRIPTION & CDIO ARRPOACH

On the design of “Innovation project - foundation”, students will have the rudiment of engineering and how to become an engineer. The teaching and training goals are focusing on:

1. Innovation concept – understand the definition and meaning of innovation. (C, D)
2. Innovative accomplishment – learn professional skills and tools using. (C, D, I)
3. Need finding & Problem scoping – ability to Figure out the real world problem & challenges, and define problems/pains and the background in detail. (C)
4. Idea generation and innovative thinking– Idea generation fluency and become an informed designer. (D)
5. Realize & implement–build up prototypes or models of the solution. (I)
6. Self-evaluation–confirm the value proposition of the solutions and the ability of competitiveness. (O)
7. Professional communication–presenting the problem statement, challenge, solution, and the unique value proposition in a formal way via oral or writing. (O)

The design of course roadmap with the innovation process and abilities training is represented in Figure 1.

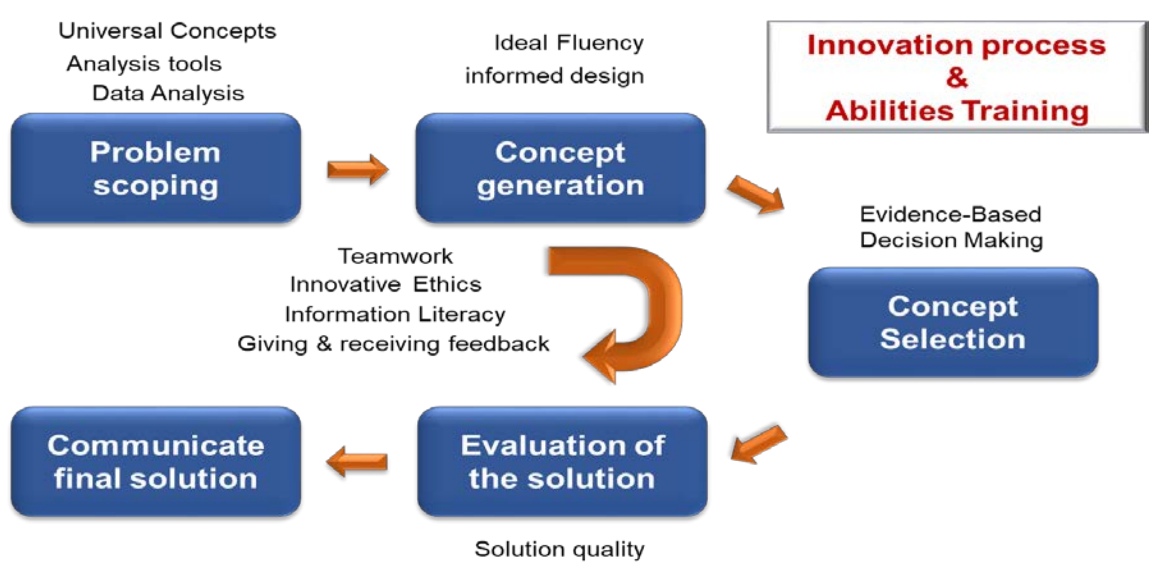

Figure 1. The roadmap of “Innovation project - foundation” module with training abilities

During the course, students learned four categories of abilities training objectives, which are: (1) engineering tools using & analysis, (2) engineering professional skills (soft skills), (3) modeling & problem solving, and (4) innovation & Design. It is believed that a successful engineer requires well training of the following 14 abilities (Figure 2.). The step by step abilities training objectives with detailed description is shown in Table 1.

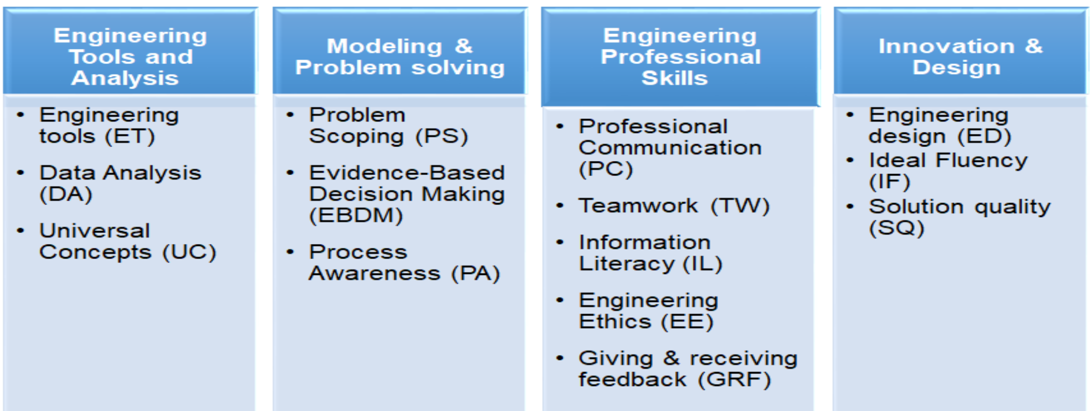

Figure 2. Four categories of learning goals with 14 abilities objectives

Table 1. Learning goals and the objectives of abilities training

Goals Category	Learning goals	Abilities training objectives
Engineering tools using & analysis	Engineering tools (ET): using software, apparatus or prototypes to support your engineering calculation, analysis, modeling and presenting your results.	ET01-Use built-in cell referencing and functions of MS Excel for the efficiency of calculations
		ET02-Select appropriate graphical representation of dataset based on data characteristics such as numerical (discrete or continuous) or categorical (ordinal or nominal)
		ET03-Justify graphical representation based on data characteristics.
		ET04-Prepare chart or table for technical presentation with proper formatting (headers, units, meaningful decimal points, appropriately scaled axes, appropriately sized marker and axis labels)
		ET05-Create a histogram with a meaningful number of bins and width/sizes.
		ET06-To collect trustworthy information, literature or data from the internet.
		ET07- Use tools or modeling package to test or simulate the engineering design. For example MS Excel, CAD software.
	Data analysis (DA): to study and finding the meaningful/useful	DA01-Describe, with calculations, the central tendency of data using appropriate descriptive statistics (mean, median, and mode).

	information from pre-existing or new data set.	DA02-Describe, with calculations, the variability of data using statistical methods (standard deviation, variance).
		DA03-Make accurate statistical comparisons or analysis across grouped data with two or more variables.
		DA04-Given independent and dependent variables, interpret or predict the performance of a solution.
		DA05-Given two variables, describe the relationship and/or calculate the strength of the correlation between these variables.
		DA06-Interpret the distribution of data in a graph.
	Universal Concepts (UC): prepare and present the information/results in a simple and direct way for clear understanding, including appropriate text description, tables or diagrams with captions.	UC01-Demonstrate an understanding of conservation principles (mass, energy, momentum, and/or charge) in a boundary system
		UC02-Describe systems or processes using schematic diagrams with inputs and outputs.
		UC03-Define systems or processes with mathematical models with simulation results.
		UC04-Calculate efficiency of a system, product, or process as it relates to cost, energy, or other engineering factors
Engineering professional skills	Teamwork (TW): to work in a synergistic way to improve efficiency and productivity and reduce mistakes. Teamwork skills include division of labor, effective communication, giving and receiving feedback and so on.	TW01-Evaluate the unique knowledge, skills and abilities of each team member
		TW02-Document all contributions to the team performance with evidence that these contributions are significant.
		TW03-Develop strategies to support interactions between teammates and learn from one another.
		TW04-Develop expectations with high-quality work and timely completion of team projects.
	Information Literacy (IL): seek, find, collect, evaluate and apply information appropriate from a variety of trustworthy sources.	IL01-Ask questions to determine what new information is needed to scope and solve a problem.
		IL02-Include citations within the text (in-text citations) that show how the references at the end of the text are used as evidence to support decisions.
		IL03-Gather information from reliable sources and being able to evaluate the quality of evidence.
		IL04-Support all claims made with evidence that is either generated or found.
		IL05-Format reference list of used sources that is traceable to original sources (APA or MLA are recommended)

	Professional communication (PC): communicate engineering concepts, ideas, decisions and professional advice in multiple ways including written, oral, visual and digital communication.	PC01-Use professional communication (written, visual, and oral), free of grammatical or spelling mistakes and in a formal tone, appropriate for engineering school and workplace.
		PC02-Make clear and complete arguments or statements by fully addressing all parts of the assignment.
		PC03-Present all visuals with captions (e.g., Figure number, table number, and brief description)
		PC04-Professionally present all visuals representations (Figures, images, sketches or prototypes) to clearly convey meaning by labeling key components to show their form and function.
	Engineering Ethics (EE): recognize how contemporary issues as part of cultural, economic and environmental factors impact engineering design and practice, and what are the obligations and responsibilities of an engineer.	EE01-Justify decisions based on the recognition that such decisions involve not only technical factors but also cultural, economic, environmental and other applicable considerations.
		EE02-Predict/identify the potential ethical dilemmas and consequences that result from implementing solutions.
		EE03-Make connections between classwork and contemporary issues that impact or are impacted by engineering practice.
	Giving & receiving feedback (GRF): giving specific and objective information for improvement; open mind to receive the idea or suggestion to improve yourself.	GRF01- Give useful and meaningful objective information for helping others to improve, including by point out blind spots, honest mistakes and misconceptions.
		GRF02- Evaluate objectively the information received, evaluate if it is reasonable, and take appropriate action.
Modeling & Problem solving	Be able to develop a clear statement of the problem, including environment, stakeholders, criteria, constraints and so on.	PS01-Explain the problem based on the synthesis of the client, user, and other stakeholder needs.
		PS02-Justify why the problem is important to solve by making reference to relevant global, societal, economic, or environmental issues.
		PS03-Explain key specifications (in terms of criteria and constraints) that address what the client wants and what the user needs.
		PS04-Identify potentially competing or conflicting needs or requirements.
		PS05-Expand or revise problem statement based on evidence found during later stages of the design process.
	Evidence-based decision making (EBDM): Use	EBDM01-Test prototypes and analyze results to inform a comparison of alternative solutions.

	evidence to develop and optimize solution. Evaluate solutions, test and optimize chosen solution based on evidence.	EBDM02-Identify assumptions made in cases when there are barriers to accessing or collecting information related to a problem.
		EBDM03-Clearly articulate reasons for answers with explicit reference to data to justify decisions or to evaluate alternative solutions.
		EBDM04-Justify chosen metrics and the corresponding assigned weights to evaluate potential solutions, based on stakeholder needs.
		EBDM05-Present findings from iterative testing or optimization efforts used to further improve the aspect or performance of a solution.
	Process awareness (PA): Reflect on both personal and team's problem solving/design approach and process for the purpose of continuous improvement.	PA01-Identify strengths and limitations in one's problem solving/design approach.
		PA02-Identify potential behaviors to improve the approach in future problem solving/design projects.
Innovation & Design	Engineering design (ED): addresses issues of creating and delivering innovative, useful, reliable and economical technical solutions to meet client wants or needs. Also, the ability to plan and schedule works, build up and test prototype and redesign based on interim evaluations.	ED01-Define the problem, criteria, constraints, and requirements.
		ED02-Be able to brainstorm multiple ideals and designs as the solutions in response to the problem statement.
		ED03-Plan and schedule the proceeding of development works
		ED04-To build up prototypes for you design.
		ED05-Test the properties of prototypes for further improvement. Sometimes, redesign is required.
	Idea Fluency (IF): to generate ideas fluently. Take a risk when necessary.	IF01-Generate a wide range of solutions including ideas not readily obvious or combinations of ideas in new ways. Explicitly use and document two or more ideation strategies (biomimicry, brainstorming, exploration of prior art, etc.) to generate ideas.
		IF02-Generate testable prototypes (physical, visual or conceptual) for a set of potential solutions.
	Solution quality (SQ): to present a high-quality solution (or design) for an engineering problem, including a detailed description, feasibility, risk, and other supporting materials, evidence, information, etc.	SQ01-Use appropriate, scientific, mathematical, and/or technical concepts, units, and/or data in solutions.
		SQ02-Justify design solution based on how well it meets criteria and constraints.
		SQ03-Justify qualities of a solution and recognize any limitations and be able to explain the trade-offs made to arrive at a final solution.

IMPLEMENT METHODOLOGIES AND CASE STUDIES DISCUSSION:

In order to cultivate freshman with the effectiveness of innovation process, soft skills/abilities with our designed CDIO teaching strategy, a series of case study were selected in different training stages, as shown in Figure 3. During the course, several teaching methods and models have also engaged in improving student learning efficiency, as following:

Self-determination theory (SDT) – as mentioned before, the lack of motivation is one of the most serious problems of students in Taiwan. How to frame motivational studies for our student is the top challenge for course design and applying CDIO structure. SDT is a motivational theory of personality, which including both intrinsic and extrinsic motivation (Deci, E. L. and Ryan, R. M. (2015)). In the meta-theory of SDT, three basic psychological needs of students are *Autonomy* - have a chance of selection but receiving orders from instructors only; *Competence* - to know that they have ability to success, sense of accomplishment is a strong driving force for autonomic learning; *Relatedness* - interact with instructors or classmate but receiving information passively.

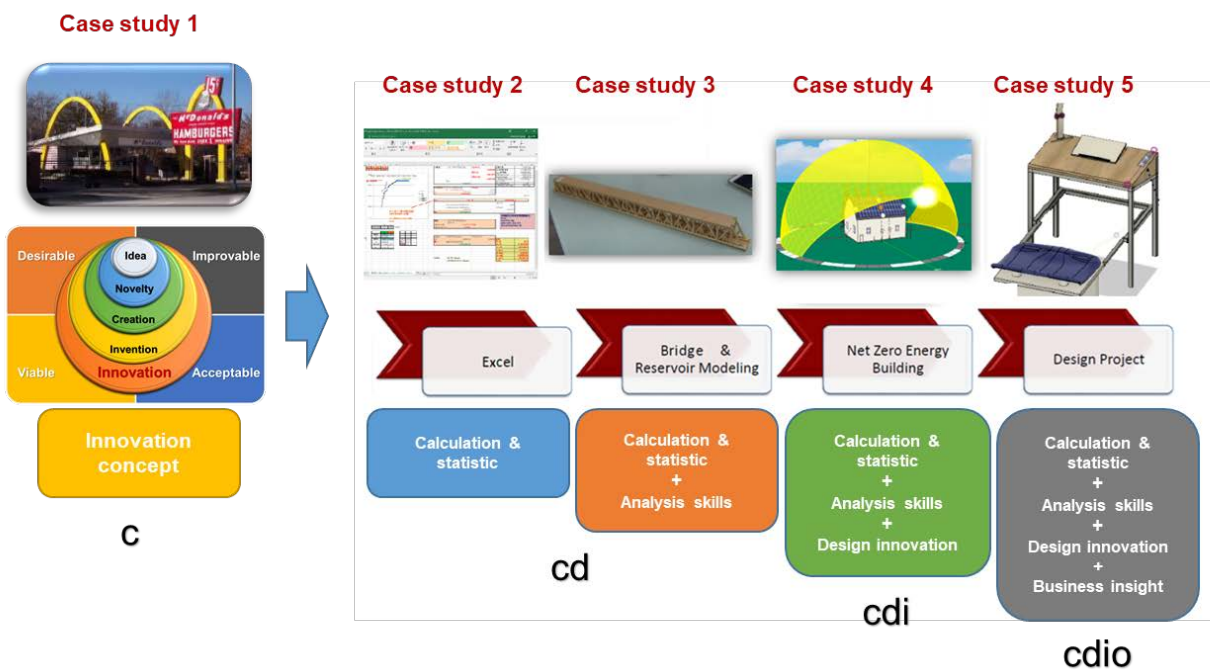

Figure 3. A series of case study for own designed CDIO teaching strategy

Bloom's taxonomy – 5 levels of learning achievements in the taxonomy are; remember, understand, apply, analyze, evaluate and create. However, from both the feedbacks of graduate students and supporting companies/industries, application ability to learned knowledge is relatively weak in our students. In the traditional teacher-centered classroom, paper examination is the most common way to evaluate the outcome of students with the level of remembering and understand the knowledge. Therefore, in this course, Bloom's taxonomy is applied for our student understanding the meaning of learning selected knowledge and professional engineering tools (Figure 4.). By designing learning activities, such as problem-based or project-based learning cases, students are relatively easy to achieve the level of apply, analyze and even create. Also, learning by operation, the student can easily understand the connecting between knowledge and real-world application.

CASE STUDY 1 (C):

The first case study was designed to build up the student's universal concept of innovation, which is a fundamental training even before the process of conceive. At the beginning of the class, the definition and difference between idea, novelty, creation, invention and innovation were explained as the key knowledge. After that, the case McDonald's entrepreneurial history has been select as a teamwork activity for the student to understand the definition of innovation. In the class, students were teamed up and working together to search the history of McDonald. After the preliminary understanding of the background, students were asked to analysis the reason for McDonald's success with the outcome of a 5-minute oral presentation. Peer review with other teams and the feedback from the instructor helped the students to gain the correct information.

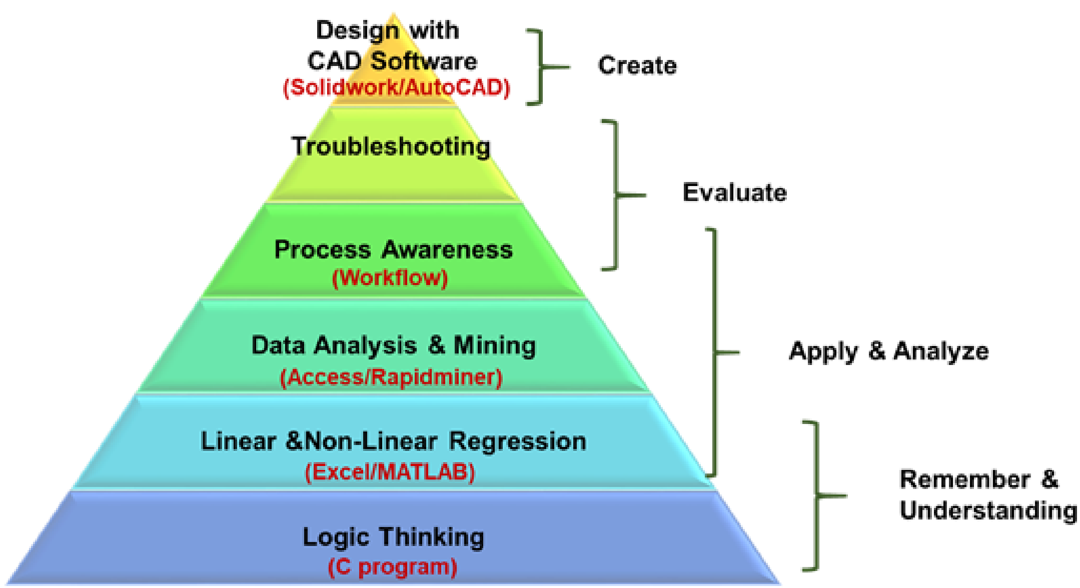

Figure 4. Alignment of learning tasks with Bloom's taxonomy using the CDIO approach

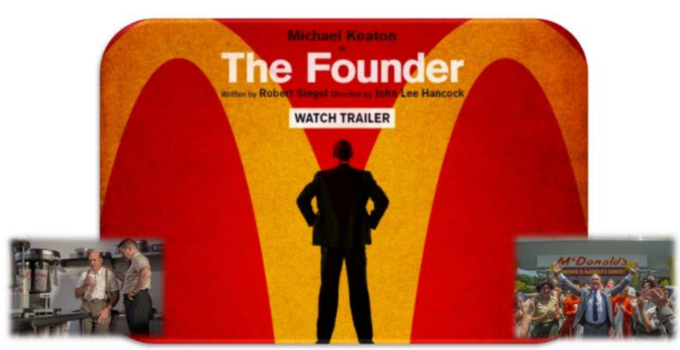

Figure 5. Case study 1 (innovation concept) – the founder, story of McDonald

CASE STUDY 2 (C, D):

To cultivate the ability of data analysis and accurate conceive process, a situational problem-based learning activity with a real-world dataset of accident statistics of firefighters was selected. Students tried to apply the skills of data analysis with multiple linear regression method to Figure out the key factors of causing death and present the analysis results with the ability of diagram drawing. After that, they are required to prepare a simple designed solution or suggestion as outcomes with the evidence of their data analysis/problem scoping results. During the activity, for solving a real-world problem with professional suggestion, students learned the application of engineering tools autonomously with strong motivation, which is good training of conceive stage with the ability of problem scoping and statement preparation. In the outcome, the student can provide reasonable suggestion by the analysis results and achieve evidence-based design. The description of the situational problem and parts of a student's analysis results are shown in Figure 6.

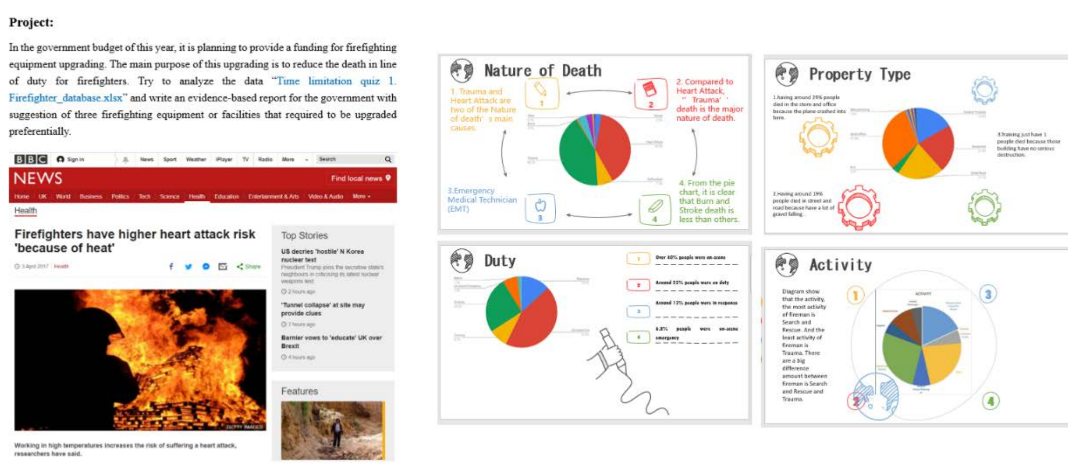

Figure 6. Topic of case study 2 (data analysis and problem scoping) and some outcomes from students

CASE STUDY 3 & 4 (C, D, I):

In the third stage, students were asked to review the ability of problem scoping and engineering tools application to understand the background of the challenge. Further, in these activities, students learned the ability of prototyping and modeling. Bridge and net zero energy building design were selected as a semi-open design projects. With expecting outcomes of several physical prototypes and digital modeling in a group, students are trained to learn by implement, testing, comparison and find out the way to improve their original design. During the case studies, to identify and list the key criteria of the user requirement is one of the core training to achieve evidence-based design and user-centered design. Some of the design results were shown in Figure 3.

CASE STUDY 5 (C, D, I, O):

At the final design project of the course, students will challenge an open-ended design with real-world topic- next generation classroom for CDIO learning environment. In this design project, students have to run the complete process of innovation (fig. 1) on their own. The first two weeks of this 4-weeks duration design project, students reviewed all the ability they learned before, to identify the criteria and constraints as the pain and limitation of all stakeholders; to run brainstorming with teammates for achieving maximum possibilities of solution ideas; to compare the pros and cons between solution ideas and narrow down to 3 reasonable and acceptable designs. In the latter two weeks, instructors introduce the meaning of “operation” in the CDIO concept. In here, students were trained to evaluate their top design with solution testing, comparison with the current solution, optimize the design detail and setting the standard manufacture process. As the outcome of their design, students had to prepare a 5 min advertisement video, a A0 size poster, and the prototype of their solution idea to join in a cross-class exhibition. In the exhibition, they have to descript their idea and solution in detail and also defend their design from the questions from both school faculties and other student teams, which is good training of professional communication on both giving and receiving sides. The photos of the exhibitions are shown in Figure 7.

Figure 7. Photos of the cross-class exhibition of the final open ended design project

ASSESSMENT METHODS

Based on the course design, several assessment methods were applied to different learning outcomes (Table 2.). The descriptions of each assessment methods are presented below:

Table 2. Assessment methods (with percentage)

Team activity	*Assignment*	*Professional expectations report*	*Time limitation quizzes*	*Design project 1 (Poster)*	*Design project 2 (Poster)*	*Design challenge – (Oral & video)*
10%	20%	15%	10%	10%	15%	20%

- Team activity:

Implement: Following from the method of the literature (Matthew W. O. (2012), the assessment method was divided to (a) monitoring form instructor (and teaching assistants), (b) peer evaluation, and (c) self-evaluation. To prevent potential internal disputes and keep students working on their own task is one of the most important issues in this section.

In part (a) instructors (and teaching assistants) guide and assist students to work as a team with 5 CATME teamwork models (contributing to the team's work; having relevant knowledge, skills, and abilities (KSAs); expecting quality; keeping the team on track; interacting with teammates), which have been transferred to students at the beginning of the semester.

In part (b) and (c), the comprehensive assessment of team member effectiveness-BARS version was selected for students to evaluate their teamwork behaviors with both peer and self- one. By doing this, students can review the concept of working as a team and reflect him/herself with standard rubrics. It is also a good private path for reflecting feelings and thoughts to the instructors.

Outcomes: In the past, around 80% of Taiwanese students confuse the idea between teamwork and division of labor, and 30~50% of the student team has had a dispute within the group. After introducing the new teaching strategy and methods, 80~90 % of our students understand the true meaning of teamwork, and also apply their personal value proposition in the team. On the other hand, less than 5~10 % of student groups have had disputes during the semester.

- Assignment:

Implement: Assignment is one of the most assessment methods through the semester. A weekly assignment is where our students implement their work and present their learning outcome in detailed after the lecture. The assignments were carefully designed in three individual sections, which are the summary of the lecture, learning goals/required abilities, and breakdown topics with answer sheets. By working on assignments, students can review what they learn from the class; finish their tasks step by step from simple to advanced one.

Outcomes: By grading weekly assignments, instructors can understand student's performance and track their learning effectiveness in detail, no meter individual or teamwork one. After applying the new designed assignments in the course, more than 80 % of our students can understand the learning goal and the process to build up their performance. When they found difficulties, 80% of our students exactly know where the problem is. It is much more direct for students to overcome the problems by themselves, or for instructors to help them.

- Professional expectations report:

Implement: Professional expectations report is applied at the end of case study 1 and 2. Students have to integrate what they learn from the 2~3 week works of the same project. It is a good chance for them to review what they did/learned before, to build up their integration ability and represent it in a formal/academic format for communication.

Outcomes: Compare with the students from other classes, our students can write original articles/reports with much more rich and relevant content, opinions or discussions in academic structure, but a listing report of their working process and simple result descriptions only.

- Time limitation quizzes:

Implement: Time limitation quiz is another assessment method different from assignments and professional expectation reports, with slightly more challenge. Two times of quizzes were implemented at the last part of case study 2 and 4, which a similar topic with 1 or 2 additional criteria/limitation were chosen, and working in a team as well. Furthermore, not like the original case study, students have been asked to finish the challenge in an hour. By introduce appropriate pressure, it is believed that students can improve their personal abilities, no matter the professional knowledge or soft skills. Agree to SDT, students will feel competence, relatedness and autonomy during the quizzes, try to know their own abilities, to accomplish goals, and to get stimulation.

Outcomes: As the expectation, most of our students try their best to demonstrate their learning effectiveness to finish the project with confidence. Student groups who complete the challenge, they do enjoy their competence; the groups who cannot succeed, usually will try to figure out where the problems are spontaneous. At this time period, it is important for instructors to listen to the way they achieve success, and to guide the one who failed. In our experience, only about 30~40% of our student groups can succeed in the first quiz, however, nearly 100% of them can succeed in the second one.

- Design project 1 & 2 (poster):

Implement: As the description of case study 3 & 4 above, not only problem scoping and design thinking, it is also important for instructors to understand the student ability of innovative solution creation. Based on the design of semi-open design project, students pay less attention to problem scoping but problem understanding, and more attention on solution design and implement. 4 rating criteria (1~5) were selected for student's poster presenting and presentation, including (1) problem understanding, (2) criteria and constraints analysis, (3) problem-solution fitting (4) communication skills.

Outcomes: Following from our course/project design, nearly 100% of the students know the structure of presentation/poster and the meaning of it; nearly 30% of them can reach 4 or 5 at all rating criteria; about 60% of them can reach the average between 3 and 4; less than 10% of them still struggling in 1 or 2 of criteria. By collecting their outcomes, it is very helpful for instructors to know where the difficulty is for our students, and have a chance to help them in the final project (case study 5).

- Design challenge:

Implement: The aim of the final challenge is to see the integration and application abilities of what our students learned during the whole semester. It is 5~6 weeks' project, which instructors and TAs helped students to review the skills and knowledge and try to apply them to challenge an advance/complete open-ended problem. The successful innovative solution/product/service should include 5 criteria with complete description: problem statement, current bottleneck, problem-solution fit, evidence-based innovative design, and solution quality, which match c.d.i.o. structure. They will present their results via 3 types of professional communication methods, such as oral presentation, video advertisement and (digital) prototype.

Outcomes: 80~90% of our student teams can finish the project with good quality solutions, also, students' progress between the final challenge and the previous one is significant. Rest of them can figure out where their week point is and the way to improve it with professional feedback.

CONCLUSION

In decades, the education strategy of 12-year basic education in Taiwan only engaged with the traditional teacher-centered environment. As a result, college graduates faced big challenge and gaps when entering into society. To solve the problem, International school of technology and management, Feng Chia university design a new module “Innovation project – foundation” combing CDIO process with self-determination theory and bloom’s taxonomy to improve the learning efficiency and also soft skills training. By completing the series of design projects in the module, the student is now able to apply the knowledge flexibly to challenge complicate real-world problems. It is also believed that the students who complete the training and once finish the credits of the graduation requirement, they can highly match the requirement and talent selection conditions of employers.

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