Introductory Mechatronics Creative Decision and Design Tools—the Design and Realization of a Mechatronics Course

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Abstract

Under globalization, enterprises are facing competition for talent and intelligence. Actually, competition for talent and intelligence is often a kind of education quality competition, especially in engineering education. Engineering education must be comprehensive and forward looking. Engineering students must always look forward in order to respond to competition in their professional careers. So they also wish to be comprehensively trained when they are in college. It is well known that hands-on experiences in engineering education are beneficial, increasing both learning and enjoyment during coursework. At ICEER 2013, we introduced an international cooperation project for engineering education between Huazhong University of Science and Technology (HUST) and Georgia Institute of Technology (GATECH). In order to promote student competence in innovative design, creative decision making, technical communication, and team work, the course Introductory Mechatronics Creative Decision and Design Tools (IMCDDT) was set up in 2011 at HUST. This course is designed to provide both interesting and relevant hands-on experiences for a wide range of topics including design processes, basic mechatronics concepts, technical communication, and working in a team environment. In this paper, we introduce the course of IMCDDT in detail by presenting its goals, contents, syllabus, teaching methods and learning outcomes. Because a mechatronics design competition program is created for students participating in the course, the competition program is also introduced comprehensively in this paper. The paper also highlights the "Four topics, Eight sessions, Three presentations and One competition" project-based mode, which is an effective interaction methodology to organize lectures and studio sessions.

Keywords: *Mechatronics Course, Creative Decision, Design Tools, Mechatronics Design Competition Project, International Cooperation*.

1. Introduction

Under globalization, enterprises are facing competition for talent and intelligence. Actually, competition for talent and intelligence is often a kind of education quality competition, especially in mechatronics engineering education. It is well accepted that mechatronics is a "synergistic combination of precision mechanical engineering, electronic control and systematic thinking in the procession of product design and manufacturing". [1] Mechatronics engineering education is comprehensive and forward looking; it is taught to a broad student population from undergraduate to graduate students [2]. Mechatronics engineering students will undoubtedly face stiff competition in their future professional careers, so they should be comprehensive trained during college. [3] The mechatronics discipline requires students to be trained in not only pre-requisites such as Automatic Control Theory and Principles of Microcomputers, but also calls for training in teamwork, hands-on building, creative decision making, innovation, and technical communication. [4]-[6] Actually, teaching mechatronics courses always comprises both theoretical knowledge and practical knowledge. [3] [7]-[10] It is well known that hands-on experiences in engineering education are beneficial, as they increase both learning and enjoyment during coursework. [11]-[12] This is usually achieved via project based learning and hands-on coursework.

In the past, many Chinese college engineering graduates were said to master theoretical knowledge very well, while seeming to lack practical competence; they sometimes were regarded as "High-intelligence, but low-creative students". [13] One of the reasons for this is the persistence of "emphasizing learning and despising practice" in engineering education in China. In order to promote student competence in innovative design, creative decision making, technical communication, and team work, a course titled Introductory Mechatronics Creative Decision and Design Tools (IMCDDT) was created in 2011 at HUST. In ICEER2013, we introduced the international cooperation project on mechatronics engineering education between HUST (Huazhong University of Science and Technology) in China and GATECH (Georgia Institute of Technology) in USA. [14] The course IMCDDT was setup in this project.

The course is set up for sophomores who have almost no experience with engineering, not to mention mechatronics concepts. Based on the theory of project-based learning, this course is designed to provide students with both interesting and relevant hands-on experiences for a wide range of topics, including design processes, basic mechatronics concepts, technical communication, and working in a team environment. Because a mechatronics design competition program is used as the final project for students completing the course, the competition program will be introduced in this paper. Furthermore, the challenges of the course administration are highlighted in this paper.

In the rest of this paper, the goals and contents of the course are introduced in Section 2, and also the credit rules for the students are introduced in this section. In Section 3 we introduce the teaching and learning methods. In Section 4, the integrated project designed for students' hands-on work and the final competition are described. Some examples related to teaching methods and learning outcomes are presented in Section 5. In section 6 we conclude the results of building IMCDDT at last.

2. The course of IMCDDT

One of the reasons that Chinese engineering students are regarded as "High-intelligence but low-creative students" is the long existence within Chinese colleges of "emphasizing learning and despising practice" in engineering education [13]. The direct consequence of this approach to engineering education is that innovative practice and creative decision competence are weak among graduates.

GATECH is well known for its achievements in engineering education in the USA (as well as in the world). Creative decisions, innovation, teamwork, hands-on experiences and technical communications are emphasized in their curriculum. In the School of Mechanical Engineering at GATECH, these qualities are emphasized in the course Creative Decisions and Design (ME2110). [15] ME2110 was developed for sophomores who usually do not yet have engineering experience. It is one of the most popular courses at GATECH; approximately 500 students select ME2110 every year. A mechatronics project is integrated into the course. In addition to attending lectures, students are required to attend studio sessions for hands-on exercises, and they must complete the team design project. At the end of the course, students present their machines in a competition that is one of the biggest educational events at GATECH each term. [16]

One efficient method to promote engineering education quality in China is to import educational resources and teachers from colleges in countries with well-developed engineering programs. In order to promote student competence in innovative design, creative decision making, technical communication, and team work, we are developing HUST's course similar to ME2110.

With help from GATECH faculty, a mechatronics course, IMCDDT—Introductory Mechatronics Creative Decision and Design Tools—was created in 2011 at HUST. The course is conducted jointly by professors from HUST and GATECH. It is designed for sophomores who do not yet have experience with any engineering practice. In the course, students complete a design competition project after they learn the theoretical methods. By the time the students finish the theoretical knowledge learning, the hands-on jobs on the design competition project, and participate in the final competition, their understanding in creative decision-making, collaboration, engineering design, and technical communication has been comprehensively trained. The process of learning in this course will provide students a good experience for their next two years of professional study.

The course is provided in each spring term for one class of students. Since its introduction, 4 classes, each having more than 50 students, attended the lectures, designed and built mechatronic devices and participated in the final competition. The course is now becoming a popular mechatronics course in the mechanical school of HUST. Pongxiang Yin, one student who enrolled in the course in 2012, wrote in his final report: "For a Chinese engineering student, it is a distinct opportunity to learn theoretical knowledge and to experience hands on job in one course. The class, as well as the designed hands on project and the final competition, provide a platform for us to promote our competence of engineering creative decision, collaboration in team work, and practice. I like the course very much".

2.1. The goals of the course

The goals of IMCDDT are focused on:

a) Build an engineering education platform for learning mechatronics, creative decision making, and design tools.
b) Train competence in innovation practice and creative thinking.
c) Provide practical experience in hands-on building, design, and team work.
d) Develop an engineering educational philosophy of solving problems via team work, do-it-yourself activities, and learning by doing.
e) Build a new engineering education model by focusing on both practical training and theoretical teaching, project driven, hands-on production, and competition-based evaluation.
f) Cultivate students' practical ability, innovative thinking ability, decision-making ability, design ability, team work spirit, and competitive spirit.
g) Encourage faculty to keep pace with well-known universities through the world in both teaching ideology and teaching methodology.
h) Build a teaching group which comprises faculty from both HUST and GATECH. The group will become a model in innovative teaching and education reform of engineering education in the mechanical school of HUST.

2.2. Contents

There are two main components of IMCDDT. One is the integrated competition project designed for hands-on work and the other is theoretical knowledge. The integrated competition project will be presented in Section 3. Here we introduce the theoretical knowledge taught in IMCDDT.

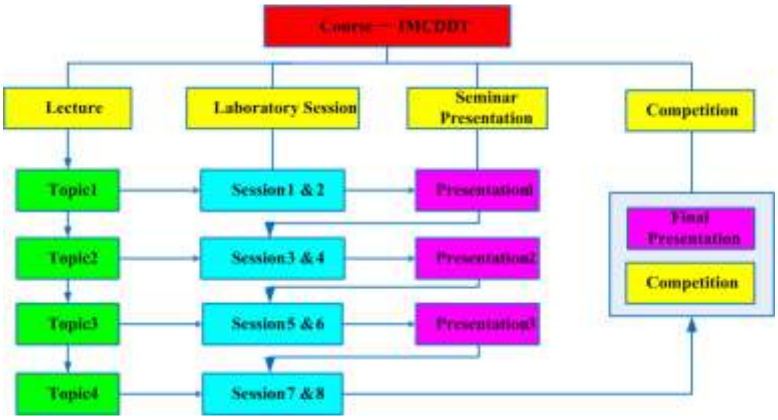

Figure 1. The theoretical knowledge structure and lecture layout.

Because it is designed as an introductory mechatronics course IMCDDT does not emphasize "how" to design a mechatronics product for a customer; rather, the course introduces only the most basic concepts on "what" a mechatronics product is, as well as "what" kinds of tools can be used to design a mechatronics product. The justification for this consideration is that the students in this course are sophomores with no practical engineering experience. We primarily want them to understand what a mechatronics product is, what kinds of mechanical/electrical components can be used to construct a mechatronics product, and what kinds of tools can be used to help design a mechatronics product. What theoretical knowledge they should learn in the following years is necessary for designing and manufacturing a mechatronics product. So the teaching of theoretical knowledge, as well as design tools is divided into four parts:

a) Tools for problem understanding

Tools for problem understanding include tools for understanding customer needs and product functional decomposition tools. In this part, students learn what tools can be used to understand customer requirements at the beginning of a mechatronics project and what tools can be helpful for transforming the requirements into product functions. In this part of the course, several tools are introduced to students: Problem Understanding Form, House of Quality, Function Tree, Function Block Diagram, and Solution Function Tables. These tools help students work effectively during the first stage of mechatronics design.

b) Tools for conceptual design

Conceptual Design usually means specification development, concept generation, and safety considerations. In this part of the course, students learn to use tools such as the Specification Sheets, Morphological Charts, Concept Evaluation Matrixes, and safety consideration guidelines. After learning this material, students extend their knowledge to design a mechatronic prototype that will fulfil customers' needs.

c) Tools for project planning

The project planning tools taught in this part of the course are Planning Tree Diagram, Gantt Chart, Prioritization Matrix, Job Responsibility Matrix, and Peer Review Forms. In this part of the course students learn how to use these tools to plan their projects.

d) Tools for technical communication

In this part of the course, students learn to communicate effectively with their team mates, managers, and customers. Methods for preparing images, writing reports, documenting sources, and editing technical presentations are taught to the students. Also, several communication tools via internet such as email, skype, QQ, and weixin are reviewed for use as technical communication tools.

The theoretical knowledge structure and lecture layout is shown in Figure 1.

2.3. Syllabus

A syllabus is an outline and summary of topics to be covered in an education or training course [17]. It is regarded as a guideline of a course. Not only teachers but also learners use it during the teaching process.

So it can be looked upon as a teaching policy. Every teacher in the same course group must obey it in order to maintain consistent teaching quality.

Before the start of the IMCDDT course, the syllabus was designed by the teaching group. A part of the syllabus for the course is shown in Figure 2. In the syllabus, the course objectives and contents, course requirements, exam and credits are designed detail.

Attendant policy for students is also list in the syllabus. It requires that students will work on teams to complete the final competition project for the course. Information needed to complete project will be disseminated during lectures. It is impossible for the professors to repeat this information on a case-by-case basis to students who miss lecture.

HUAZHONG UNIVERSITY OF SCIENCE AND TECHNOLOGY
SCHOOL OF MECHANICAL SCIENCE AND ENGINEERING
Syllabus

Course: Introductory to Creative Decision and Design Tools for Mechantronics System
Hours: in class 32 hours, competition design project 8 weeks.
Lecturers: faculties from HUST and USA.
Student: Mechanical Engineering.
Pro-knowledge: Physics, Engineering Graphics, Fundamentals of computer technology.

1. Course Objectives and contents

To provide a platform for students of learning basic creative and innovation tools. To cultivate students' creative decision, technical communication, team work, and hands on ability through theoretical knowledge learning and attending a designed competition project.

(1) To learn the fundamental procedures for solving engineering design problems;
(2) the essential details of analyzing, synthesizing, and implementing design solutions with flexibility, adaptability, and creativity;
(3) the techniques which allow an engineer to tackle new, unsolved, open-ended problems.
(4) To learn by doing through team and individual projects and assignments.

2. Course requirements

(1) To learn the basic tools used for investigating of engineering project, and also using these tools in assigned competition design project;
(2) To learn the developing procedure of engineering project and using it in assigned competition design project;
(3) To learn skills and tools of technical communication in a team work environment and using these tools to complete the assigned competition design project;
(4) To learn how to prepare the technical documents.

3. Lectures and Contents

(1) Lectures

There are 10 Lectures taught in 20 hours, three presentation in 12 hours, and a assigned competition design project completed in 8 weeks.

(2) Contents and time suggestion.

Chapter 1 Introduction to Mechatronic Design	1hour
Chapter 2 Understanding Customer Needs	2 hours
Chapter 3 Product Functions	1 hour

Figure 2. A part of the Syllabus of IMCDDT.

3. Integrated project and competition

A unique aspect of the IMCDDT course is that an integrated mechatronics design project, and a final competition are carefully designed into the course. The objective of this project and competition is to create both interesting and relevant hands-on experiences for a wide range of topics including design processes, basic mechatronics concepts, technical communication, and working in a team environment. These are described next.

3.1. Integrated project and the final competition

The carefully prepared mechatronics design project that is integrated into the course is used to achieve most of the course goals. Every student is on a team of 3 or 4 students. There is no leader in the team. Every member in a team possesses his/her own sub-tasks, and also he/she should collaborate with other members to integrate his/her task with the overall project tasks.

The project topic varies every year in order to keep the contest fun, interesting, and current. But the basic functions that the student machines must perform remain constant. The reasons for this are: (1) the supply kit and tools that are provided to the students can be used for many terms, saving money; (2) ease of formulating the project; (3) facilitate the organization of the final contest.

To create a fair and interesting competition while introducing the students to design in the face of conflicting requirements, a number of design constraints are placed upon the student devices. For example, except for the actuators provided in the supply kit, each team may buy no more than one actuator and spend no more than one hundred RMB to buy construction materials. Each team's designed device must have dimensions smaller than 600x400x600mm (length x width x height). Students must also consider the aesthetics of their device because they will be evaluated by judges.

Typically, the functions of student machines include:

a) Moving the machine forward/backward and left/right;
b) Picking up and laying down objects;
c) Sensing objects;
d) Depositing items at target locations;
e) No more than two other movements defined by students themselves based on their designs.

The design project is assigned to students at begin of the course. At the same time, the students are randomly assigned to different teams. Information required to complete the project is disseminated during lectures. In the eight-week project period, students are required to design the mechatronic device using the methods presented in lectures. They also must construct the devices using the supply kit and facilities that are provided. Because it is a first building experience for many students, the construction task is a big challenge to them.

In addition, the students are asked to document the process of the design and construction and to present design reviews to the class. Three presentations are given by each team during the project. That is

a) The first one is at the start of the second week. Each team introduces their draft design plan and gets suggestions from faculties and other teams;
b) The second presentation is at the end of the third week. At this time each team shows their refined design plan and introduces their plan for constructing the machine. As before, faculties and other students give some suggestions to them;
c) The last presentation is after the eighth week and before the final contest. In this presentation, each team introduces their outcomes of the course lectures and their design project hands-on work.

After a student team finishes the design and construction of a mechatronic device, they are awarded entry into an end-of-semester competition. Prior to the competition, student machines are shown and judged in a science fair based on aesthetics, ingenuity, and the quality of the presentation of their devices. During the contest, two student machines work together to complete a task in a limited time period. The two machines are collaborators and competitors. One machine can not disturb another one's work. After the contest, each machine gets its own points according to the amount of work it performed. There are two opportunities for every student team participating in the contest.

3.2 Supply kit and tools for hands on task

The basic components necessary for students to construct their machine are provided in a supply kit, which is shown in Figure 3. Various electro-mechanical and pneumatic components, as well as a stand-alone controller with remote operational box are included in the supply kit.
Also, some machine tools and various hand and electric tools are included in supply kit for the students' hands on tasks. Figure 4 shows the construction tools.

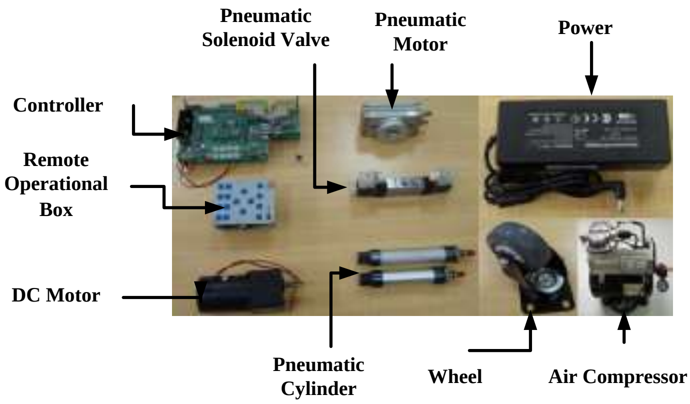

Figure 3. The components of the supply kit.

Figure 4. The construction tools.

3.3 Background and topics design for competition

The background scenario and topic used to frame for the competition varies every year to make it interesting and challenging. Usually the background and topic is inspired by popular social events. In order to ensure the selected background and topic is interesting enough for students, students who attend the course are invited to design the background and topic for the subsequent class. And this is a sub-task for students submit in their final reports.

In 2012, many places in China suffered flooding, so the topic of the competition was set to design a rescue vehicle to save victims from an island surround by the flood, and to send food and supplies to the island.

In 2013, there was a big earthquake in Sichuan, China. That year we set the topic of designing a rescue lifting truck to save victims on a damaged road, close to a mountain, that was blocked at both ends by fallen rock.

At the end of 2013, China sent a moon rover, Jade Rabbit, to moon. So the topic in 2014 is certainly set to be the design of a lunar vehicle, and the competition is moon surface exploration.

Figure 5 shows the competition fields in 2012 and 2013 respectively.

2012 2013

Figure 5. Competition fields.

4. Teaching and learning

As mentioned in Section 2, the course goals of IMCDDT are mainly realized by theoretical teaching and practise teaching. As shown in Figure 1, the theoretical teaching is provided by in class lectures, comprising 4 topics. The practise teaching is comprised of Eight laboratory sessions, three presentations, and one competition. So, the theoretical and practise teaching together form "Four topics, Eight sessions, Three presentations and One competition (FETO)" in the project-based teaching and learning mode. Here we can find other implies of "FETO": (1) the course of IMCDDT is somewhat of "feto" within the mechatronics curriculum in HUST's Mechanical School; (2) a student who selects the course of IMCDDT is somewhat of "feto" to mechatronics discipline; and (3) a teacher who teaches the course of IMCDDT is somewhat of "feto" to FETO mode.

The links and mapping relationship in FETO mode can be seen from Figure 1, that is

a) One topic of theoretical teaching corresponds to two laboratory studio sessions;
b) Two studio sessions correspond to one presentation. (The fourth presentation is integrated in the final competition!)
c) A final presentation integrated in the final contest follows the eight weeks period studio session.

In practice, the four topics of theoretical knowledge are optimized around the design competition project. Professors must teach students the specific tools they need to use to complete each sub-task at every stage of constructing their machine. During the same time, students learn how to use these tools effectively to complete the project step by step. The procedure is an interactive action done by teachers and students.

During student presentations, teachers can assess how well their students understand the theoretical knowledge. And, each presentation offers the students a good chance to show their comprehensive competence in creative decision, innovation thinking, team work and technical communication.

The final competition provides not only a stage of examination for the course, but also sustains the interesting and competitive aspects of the course.

5. Examples

The course has been presented to students 3 times, in spring term of 2012, 2013 and 2014. The course has been growing popular in the mechanical school in HUST. Limited by the supply kit and tools as well as other educational resources, many students who want to select the course cannot be admitted. Here are some examples related to the course on setup, teaching, learning, designed projects, and final contest.

The course syllabus is the programmatic document to a course; it defines the goals, contents, exam, attendance policy and the related rules of the course. So in the beginning of course development, the syllabus was designed such as shown in Figure 1.

Except for the course syllabus, other documents such as the teaching plan and calendar, requirements of practice project, record of presentation, record of competition, are all designed before the course was first provided in 2012. Figure 6 shows these documents.

Figure 6. Teaching documents of the course IMCDDT.

In the last three years, four teachers from GATECH were invited to give lectures on the theoretical knowledge, studio session, and presentations. Figure 7 shows some pictures of the lectures.

Figure 7. Scenes of the lectures.

Presentation is a necessary tool for students reporting their achievements. Figure 8 shows scenes of student presentations.

Figure 8. Scenes of student presentations.

Hands-on work in studios is also necessary for students to complete design project. It is also important for practical competence training. Figure 9 shows students constructing the machine in studio.

Figure 9. Student performing hands-on work.

The final contest in the end-of-term is the most exciting event of the course. Students take their carefully-manufactured machines to the studio, present them to judgers, and compete with others' machines. Figure 10 shows the competition scenes.

Figure 10. Competition scenes.

6. Conclusion

One efficient method for promoting engineering education quality in China is by importing educational resources and teachers from colleges in countries with well-developed engineering programs. The course of Introductory Mechatronics Creative Decision and Design Tools in HUST was created via collaboration between Huazhong University of Science and Technology and Georgia Institute of Technology. This course is designed both to be interesting and to offer relevant hands-on experiences for a wide range of topics including design processes, basic mechatronics concepts, technical communication, and working in a team environment. The course has proven to be successful for sophomores who have no experience with mechatronics engineering knowledge. Also, the teaching and learning practise shows that the "Four topics, Eight sessions, Three presentations and One competition" project-based mode is an effective interaction methodology to organize lectures and studio sessions.

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