A CDIO-Based Social Manufacturing Laboratory: Prototype for CPSS-Based Production Processes

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Abstract

CDIO is an innovative educational framework for producing the new generation of engineers by providing students with engineering and business fundamentals in the context of Conceiving-Designing-Implementing-Operating real-world systems and products. Social manufacturing is an emerging form of making and marketing customized products by 3D printers and crowdsourcing in cyberspace. A CDIO-based Social Manufacturing Laboratory (CDIO-SML) that integrates 3D printing techniques for additive manufacturing and e-commerce for marketing has been developed and described in this paper. The lab consists of five platforms for 1) teaching integration, 2) requirement acquisition, 3) interactive design and innovation, 4) manufacturing and production processes, 5) cyberspace-based marketing and operations. These five platforms facilitate product development from the requirement, design, manufacturing, marketing, to services. Each student participates in the whole process of the product life cycle and plays the roles of 1) conceiver, 2) product designer, 3) process implementer, and 4) system operator. Multiple teams are allowed to design and make multiple products in the lab simultaneously. And, the training objectives of CDIO-based Social Manufacturing Courses (CDIO-SMC) based on CDIO-SML are described in detail. Finally, an application case of unmanned aerial aircraft training is drawn out. The lab is a typical cyber-physical-social system (CPSS) that enables students to hand on and experience the entire process of collecting product requirement, conceiving, designing, developing, and manufacturing, and marketing, and providing product services of pre-sale, in-sale, and after-sale stages.

1. Introduction

CDIO is an innovative educational framework for producing the new generation of engineers with ability to Conceive, Design, Implement, and Operate real-world entities by integrating a comprehensive set of personal and interpersonal skills, and process, product, and system building skills with disciplinary knowledge [1-3]. Essentially, CDIO is promoting "learning by doing" and "project-based education and learning", and many experts and organizations consider this approach as the direction for engineering education development now and in the future [4-5]. For example, by taking product's life from research to utilization as its carrier, CDIO aims to enable students to study engineering through a proactive, personal, precision, and organic way, to develop student's engineering capability, professional ethics, academic and operational knowledge, problem-solving skills, life-long learning ability, teamwork ability, communication skills and the ability to control large-scale systems [5-9].

CDIO inherited the thinking of engineering education reform in Europe and America in

1990s [4]. With funding from the Wallenberg Foundation, MIT joined three Swedish universities to form the CDIO Initiative in 2000 [6]. The CDIO Initiative was developed with input from academics, industry, engineers and students, its activities are based on two documents, the CDIO Syllabus and the CDIO Standards respectively [8, 9]. In 2014, its 10th anniversary was celebrated in UPC Barcelona by over 100 engineering schools from USA, Europe, Canada, UK, Africa, Asia, and New Zealand.

Education of social manufacturing would be an ideal for applying CDIO approach. A emerging direction of manufacturing based on new techniques, production processes, business models, such as 3D printers, mobile devices, searching-as-producing, outsourcing and crowdsourcing, etc., for making massive personalized products, social manufacturing is considered by many as a production revolution for meeting demands by connecting and operating related parties in Cyber-Physical-Social Spaces or Systems (CPSS) [10]. Social manufacturing involves intensively with CAD/CAE/CAM, Internet, social media, Internet of Things (IoT), big data, cloud computing, knowledge automation, real-time bidding, computational advertisement, and many other intelligent technologies and methods that are new and require training and education of both students and teachers [10-13]. In many ways, social manufacturing is not only an opportunity for research, development, commercialization, but also a challenge of interdisciplinary and innovative education teaching for students, and teachers, as well as organizations. Due to its unique background, function, and operation, development and deployment of social manufacturing courses have many problems, such as unknown training targets, outdated teaching content, single teaching method, and less teaching practice [10]. How to construct, teach and learn well these courses is a difficult task to be completed at present.

At present, there are few reports on the application of CDIO in the teaching of social manufacturing. It is an urgent need in many schools around the world to set up the CDIO-based Social Manufacturing Laboratory (CDIO-SML) and CDIO-based Social Manufacturing Courses (CDIO-SMC). Therefore, here we propose an implementation scheme of CDIO-SML based on CDIO's teaching philosophy and standards, in which the students fully participate in the whole life process of individual product project by crowdsourcing and other forms. Under CDIO-SML and CDIO-SMC, through the whole process of product design, research and development and marketing promotion, the students can be guided to actively explore, analyze, and solve engineering problems, and to achieve personalized real-time production, and ultimately to produce the real products which can actually be utilized by customers.

2. Framework of CDIO-based Social Manufacturing Laboratory

Fig. 1 presents the general lifecycle of a product that includes five stages for concept, design, development, test/production, and operations. At concept stage, potential user or market demands are required and corresponding requirement specification documents are obtained; At design stage product diagrams and general specification documents, and so on, are derived; At development stage, detailed specification documents are written and all subsystems are prepared; At test/production stage, product prototype is made and tested based on all design documents and integration of all subsystems; Finally at operation stage, marketing, promotion, maintenance, support, etc. are conducted.

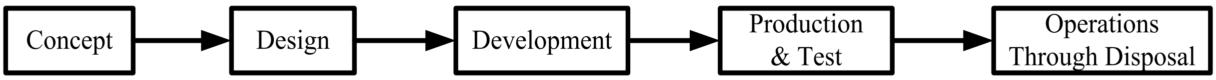

Fig. 1 Product development process

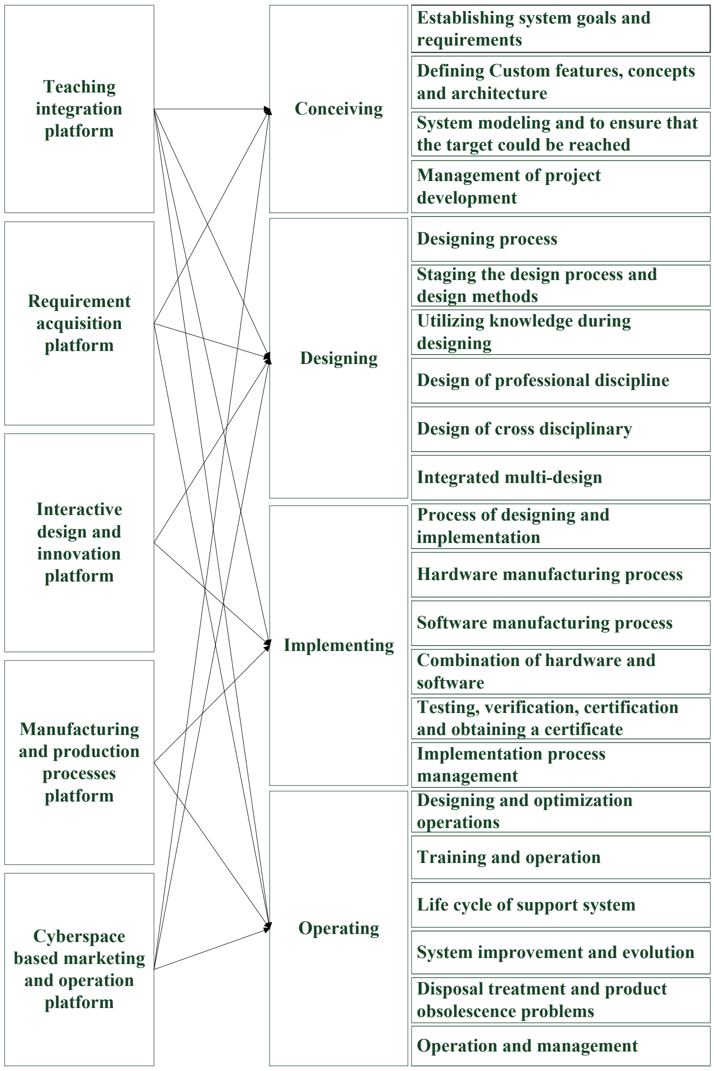

Fig. 2 Relation between CDIO-SML platforms and the CDIO process

In CDIO-SML, we have integrated the CDIO engineering education approach and social manufacturing framework together and through five platforms: teaching integration platform, requirement acquisition platform, interactive design and innovation platform, manufacturing and production processes platform, and cyberspace based marketing and operation platform. The relation between CDIO and these platforms are shown in Fig. 2. These platforms are illustrated below.

1) Teaching integration platform

This platform can integrate, manage and adapt a variety of teaching resources with customization features including e-learning systems, virtual training or simulation systems, online to offline teaching laboratories, etc. The platform is employed for the management of handouts, simulation, courseware, practice, exams, and students, and it covers all teaching tasks of the required courses of related product projects. After learning all task-specific knowledge points involved in a CDIO product project, students can access and learn all needed knowledge and skills to complete the project, for example, the application of 3D printing and related manufacturing equipment. As illustrated in Fig. 3, the platform contains two parts：

(1) Theoretical knowledge teaching module

To teach theoretical knowledge involved in the process of engineering projects, such as digital circuits, analog circuits, basic control principles and others.

(2) Practical knowledge teaching module

To teach the operation of a number of manufacturing tools and standardized training, including 3D printing and other related manufacturing practice.

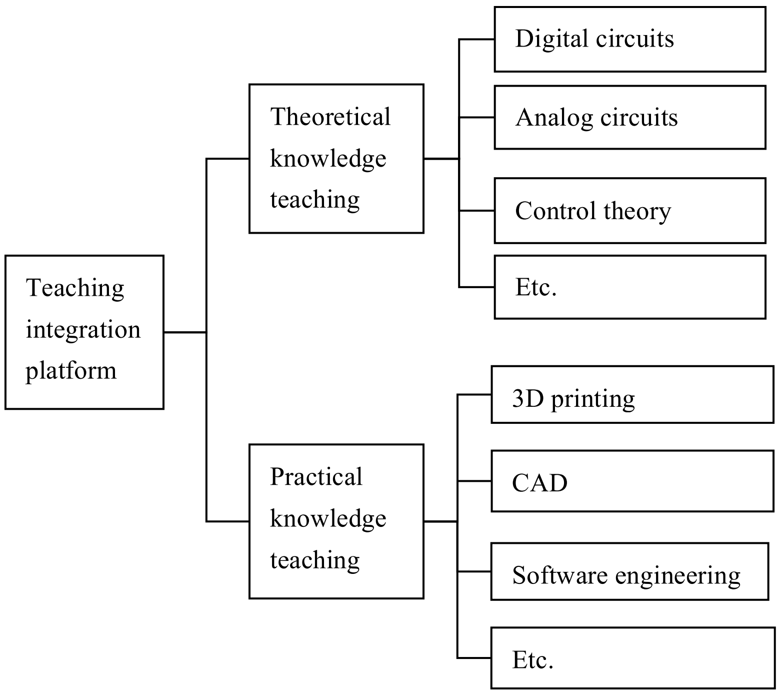

Fig. 3 Structure of the teaching integration platform

2) Requirement acquisition platform

This platform has two main functions: 1) to collect the detailed product demands from Internet communities for e-commerce and data mining activities in the project requirements gathering phase; 2) to analyze crowd-funding conditions and market feedback in product promotion stage. Fig. 4 shows the platform structure.

(1) Project requirements gathering module
This module will automatically produce a report of all collected requirements, and then based on the discussion and vote of students, the requirement specification is developed. The specification document will be utilized to verify and validate the design.

(2) Data mining module
When a crowd-funding is launched, or after a product goes to the market, consumer's comments can be collected. Various detailed requirements can be obtained and adjusted timely according to the market information from potential end users, retailers, opinion leaders, et al.

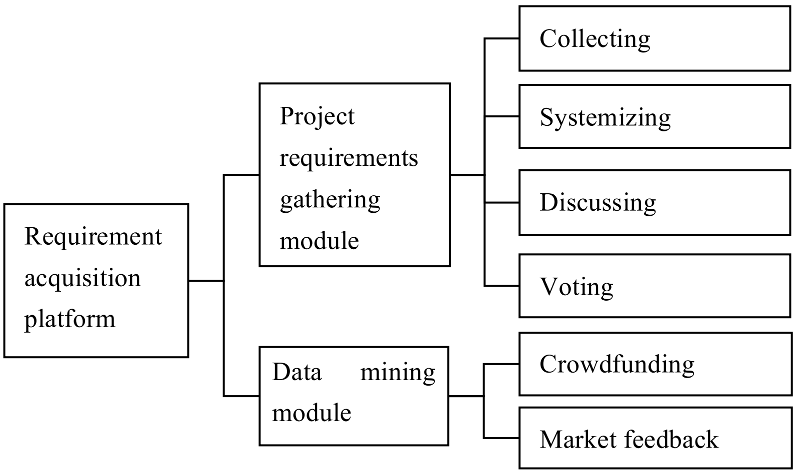

Fig. 4 Structure of the requirement acquisition platform

3) Interactive design and innovation platform
Based on this platform, students can discuss, improve trial manufacture, and determine the final product design by group discussion and ballot based on the e-commerce platform and online interaction. Fig. 5 shows the iterative procedure on this platform.

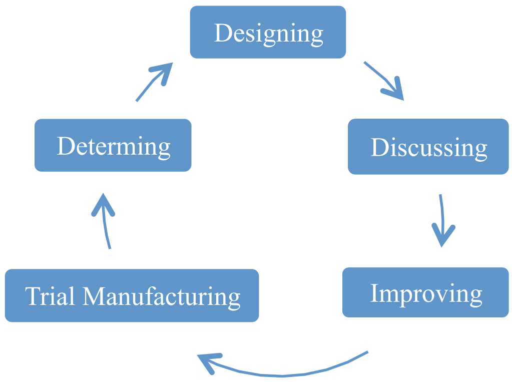

Fig. 5 Operational flow of the interactive design and innovation platform

4) Manufacturing and production processes platform
This platform is applied for product development, production, assembly, and commissioning. It makes the design documents transformed into an actual product, including development,

hardware assembly and debugging, software programming and debugging, joint testing, etc.

Fig. 6 General workflow of the manufacturing and production processes platform

5) Cyberspace-based marketing and operation platform

This platform includes an online to offline (O2O) product store and a product operation tracking system, and works when a product is put on sale. Based on this platform, the collected user feedback during the period of marketing, promotion, maintenance, and support can be sent to the product team to improve and perfect the product design and functionality. The structure of this platform is shown in Fig. 7.

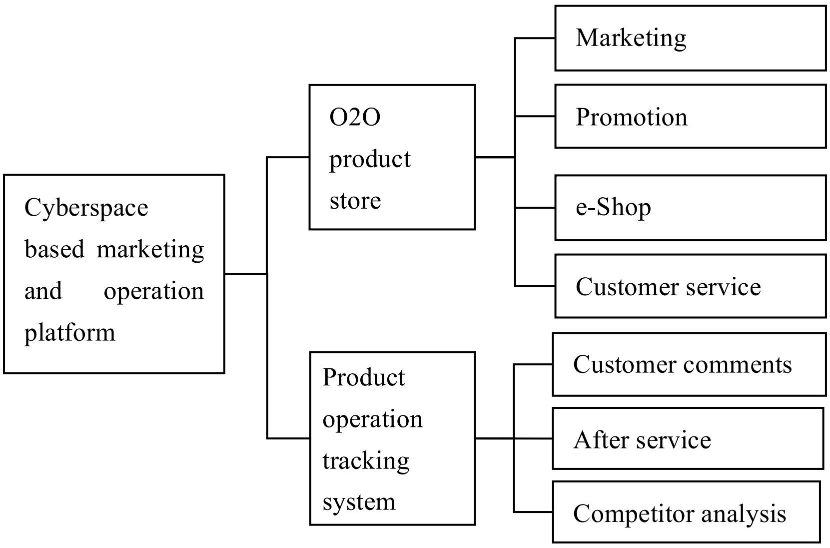

Fig. 7 Structure of the cyberspace based marketing and operation platform

3. Student roles in CDIO-SMC

Under the framework of CDIO-SML, we constructed a system of CDIO-based social manufacturing courses (CDIO-SMC). According to the CDIO engineering education model, there are four roles for all students: conceivers, product designers, process implementers and system operators. Each student participates in the whole product life cycle and plays all of the four roles.

1) Conceivers

Conceivers collect product demand from the requirement acquisition platform from potential end users, the e-commerce system, and data mining system, and propose a requirement specification. To take the unmanned aerial vehicles (UAV) course as an example, these students in the UAV CDIO-SMC may propose many questionnaires through some social network sites or analyze user comments on various UAVs by several large online shopping sites.

2) Product designers

Based on the requirement specification, product designers make a general specification for both hardware and software, and develop some trail products by 3D printers. All designers work on the interactive design and innovation platform in several groups. Some computer aided design and computer aided process planning software tools can be used for UAV design for good user experience.

3) Process implementers

The process implementers maybe generally divided to three groups: hardware assembly, software programming, and testing, and produce various customized end products. The students in hardware team of UAV course may build components from printed circuit boards, chips, and GPS modules, and the students in software team of UAV course code flight control applications under the embedded operating system, and finally they make a UAV prototype product through many test runs.

4) System operators

The system operators mainly promote their end products through an O2O store on the cyberspace-based marketing and operation platform, and also collect feedback information from an after service system. For system operation, these students of the UAV course may prepare not only product specifications and promotion brochures, but also a business plan for venture capital.

4. General design of CDIO-SMC

To practice CDIO engineering education mode in the social manufacturing course system, we present the general design of CDIO-SMC from the four viewpoints: teaching objectives, content, technology, and experimental teaching.

1) Teaching objectives

First we try to integrate knowledge and skill training together and all students can learn how to initiate a project to make a product that is approved by the market. Second, we hope they can make full use of various internet resources: search engine, e-commerce system, e-shop system, etc. Third, all students will understand the concept, framework, and implement of social manufacturing. Finally, all students can experience four roles of CDIO education mode.

2) Teaching contents

The contents of CDIO-SMC include the concept, framework, platforms of social computing and CDIO-SML, application of 3D printer to trial manufacturing, electronic circuit, control algorithms, mechanical design and theory, marketing, etc.

3) Teaching technology

In our CDIO-SMC, the 3D printing technology, multimedia network technology, information network technology, video teaching, and other many modern teaching technology will be applied to make all lectures intuitive, vivid, and impressive.

4) Experimental teaching

The tasks of experimental teaching are defining experimental teaching objectives, designing experimental content and procedure, determining reasonable class hours; proposing a teaching outline and experimental guideline, and directing and helping students to solve problems during their experiments.

5. An Application in unmanned aerial vehicles (UAV)

The UAV products are used as an application case for CDIO-SMC. At the first phase, the related theoretical knowledge course have been taught in two weeks, and as shown in Fig. 8 students work as conceivers to present their customized product requirements, such as the size, style, application scenarios, load, endurance, etc. The conceivers may also utilize the e-commerce system and data-driven requirement analysis system to define product design based on marketing requirements. At the second phase, the practice stage begins. The role of students is converted to designers. The designers determine their general design and may also try producing to verify actual performance by 3D printers as shown in Fig. 9. At the third phase, the students' roles become implementers, and Fig. 10 shows the pictures of UAV assembly and a test run. At the fourth phase, their roles are converted to the operators and they design a good package for the end products, and prompt the UAV by online or offline activities as shown in Fig. 11.

Fig. 8 Students as conceivers discuss and collect UAV product requirements

Fig. 9 Students as designers vote final product design and trial produce by 3D printers

Fig. 10 Students as implementer assemble UAVs and prepare a test run

Fig. 11 Various customized UAV end products

6. Conclusion

CDIO is an innovative educational framework for producing the new generation of engineers by providing students with engineering and business fundamentals. Social manufacturing is an emerging industry of making and marketing customized products by 3D printers and crowdsourcing in cyberspace. This paper presents a CDIO-based Social Manufacturing Laboratory (CDIO-SML). The five platforms, the roles of each student and training objectives of the CDIO-based Social Manufacturing Courses (CDIO-SMC) based on CDIO-SML, and an application case of unmanned aerial vehicle manufacturing are described in detail. Based on CDIO-SML, through the whole process of product design, research and development and marketing promotion, the students can be guided to not only actively explore, analyze, and solve design engineering problems, and but also achieve personalized, real-time, economic production utilizing additive manufacturing technology, in particular, 3D printing technology, and ultimately to produce the real products which can actually be sold and used. The lab is a typical cyber-physical-social system (CPSS) that enables students to hand on and experience the entire social manufacturing process.

Acknowledgements

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