Review of CDIO research in China: from 2005 to 2011

Yanqing Wang, Zhongying Qi, Ziru Li, Jie Yu & Yuying Zhai

Harbin Institute of Technology
Harbin, People's Republic of China

ABSTRACT: After more than 10 years' progress, Conceive-Design-Implement-Operate (CDIO) is now a successful and well-accepted engineering education model worldwide. A process of engineering education reform has existed in China, including a strategy for adopting CDIO, since 2001. Through, for example, scientometrics and social network analysis, 512 CDIO-related papers by Chinese scholars from 2005 to 2011 were analysed to grasp how CDIO has developed in China. The outcomes on CDIO were studied from the numbers of papers a year, involvement of university groups, numbers of cited papers, etc. Also, the co-occurrence network of CDIO-related keywords was constructed and analysed. Taking Shantou University as an example, the contribution by Chinese scholars was analysed from the introduction, implementation and innovation aspects. Finally, some problems hindering CDIO development in China are addressed and suggestions for institutes, government and industry are proposed to help promote the development of engineering education in China, as well as in other developing countries.

INTRODUCTION

As a global problem, engineering education reform has drawn significant attention from the government, industry and academia in developed countries [1]. In the USA, engineering education provides timely and efficient technical support for the process of industrialisation [2]. In Germany, engineering education plays the role of providing industry with large quantities of high-quality technicians to adequately meet industrial human resource requirements [3]. In the United Kingdom, professional qualifications assigned by the ECUK (Engineering Committee of the United Kingdom), academic qualifications instituted by engineering educational institutes, and vocational qualifications granted by industry are equally accepted, which indicates the maturity of engineering education in the UK [4].

In order to maintain the consistently high pace of economic development, China has to rely on technological innovation and educational reform [5]. In recent years, with the efforts of the government, industry and institutes, engineering education reform has been a prominent achievement. In August 2001, the Ministry of Education (MOE) approved establishing 35 national pilot schools for software. Some considerable achievements and valuable experiences have been acquired in the process of cultivating practical software engineers and reforming the education system [6].

In 2006, MOE and the Ministry of Finance launched a project named Plan for Establishing National Pilot Higher Vocational Institutes. The Plan strongly promotes the development of higher vocational education and strengthens the ethos of institute-industry co-operation, and it serves society. In April 2008, the Higher Education Bureau of the MOE formed China's CDIO Research and Implementation Committee, officially promoting the development of CDIO in China.

Conceive-Design-Implement-Operate is a new engineering education model that was developed in 2001. It is an innovative educational framework for producing the next generation engineers. It provides students with an education stressing engineering fundamentals set in the context of *conceiving, designing, implementing, operating* real-world systems and products [7][8]. In 2004, the international co-operation organisation Worldwide CDIO Initiative was founded. In January 2011, as the founder of CDIO and a member of the American Academy of Engineering, Professor Edward F. Crawley was awarded the Bernard M. Gordon Prize, which is recognised as the *Nobel Prize* of engineering.

So as to carry forward the functionality of CDIO and beyond, to learn something from the experiences and lessons, it is necessary to inquire as to the development situation of CDIO in China. The CDIO Initiative was introduced to China in 2005 and its implementation was launched at Shantou University [9]. Its College of Engineering developed CDIO-based curricula for all the five programmes of its four departments in 2006, and Shantou University was accepted as the first worldwide CDIO collaborator in China. Two years later, Tsinghua University and Beijing Jiaotong University joined. Then, CDIO gradually attracted attention from more and more universities and scholars in China. The first national CDIO pilot implementation group of 18 universities was officially formed in December 2008 and the second group of 21 universities was officially agreed in March 2009.

METHODOLOGY AND DATA SOURCE

Scientometrics is the science of measuring and analysing science. In practice, scientometrics is often done using bibliometrics, which is a measurement of the impact of (scientific) publications. Modern scientometrics is mostly based on the work of Derek J. de Solla Price and Eugene Garfield. The latter founded the Institute for Scientific Information, which is heavily involved in scientometrics analysis. The authors of this article applied the method to the statistics of the attributes and classifications of the papers.

Social network analysis is a view of social relationships in terms of network theory: networks consist of nodes and ties (also called edges, links or connections). In its simplest form, a social network is a map of specified ties between the nodes being studied. The map is often displayed in a social network diagram, where nodes are the points and ties are the lines. To determine Chinese scholars' focus on CDIO, the co-concurrency of keywords was analysed using this approach.

The first data source for this research was China National Knowledge Infrastructure (CNKI, http://www.cnki.net), a professional digital publication database in China. The document types include academic journals, doctoral and Master's dissertations, proceedings of conferences, books, newspapers, patents, etc. So far, the number of users of CNKI exceeds 40 million and the number of yearly downloads is more than 3 billion. The second data source is the two CDIO official Web sites, http://www.cdiochina.com in China and http://www.cdio.org worldwide.

These Web sites publish CDIO-related standard documents, news, international and domestic affairs, conference information and downloadable papers. Lastly, our data source includes 512 publications published by Chinese scholars before 20 July 2011. From CNKI, 483 journal papers and five degree dissertations, the titles of which all contain *CDIO* were downloaded. From China's CDIO official Web site, 13 more papers were collected. Additionally, eight conference papers and three reports from the Internet were found.

OUTCOME ANALYSIS OF CHINESE SCHOLARS AND CDIO

Yearly Paper Publication

The distribution diagram of CDIO-related papers published from 2005 to 2011 is depicted in Figure 1. The statistical data show that research on CDIO in China started about five years after CDIO first emerged. Although CDIO was proposed early in 2000, Chinese authors did not publish any related papers until 2005. Fortunately, the numbers of publications show an increasing trend. Data collection finished on 20 July 2011. Considering proportions, the number of papers in 2011 will keep on rising.

Productivity by Different University Groups

In order to grasp the CDIO research status for different levels of Chinese universities, the data are summarised into the following four categories: *Project 985* (launched by China's MOE in May 1998 to burnish some universities to make them become world-class and high-level research-orientated universities; so far there are 39 universities in this group), *Project 211* (initiated by China's Government in February 1993 and which was a big part of the strategy to *vitalise the nation by science and education* and orienting for the 21st Century; 112 universities have been included to date), the *first national CDIO pilot group*, and the *second national CDIO pilot group*.

The published papers by these four groups were summarised and the results are shown in Table 1. Since the first national CDIO group was formed earlier than the second one, the number of papers by the authors in the first group is much larger than that of the second group. However, the numbers of papers published by the authors from Project 985 and Project 211 universities are not as satisfactory, and do not match their higher capacity for research and pedagogy.

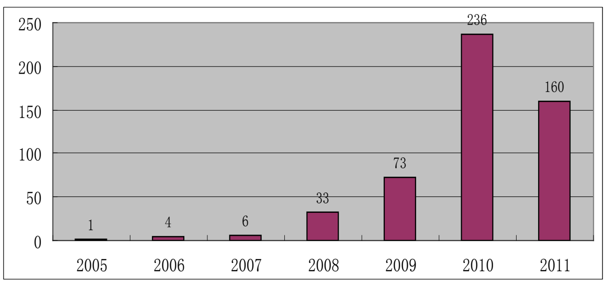

Figure 1: Summary of papers by publication year.

Table 1: Summary of papers published by different university groups.

Group	Number of Papers
Project 985	39
Project 211	64
1st National CDIO Pilot Group	116
2nd National CDIO Pilot Group	69

Indexing Situation of Published Papers

Since CDIO theory was introduced to China in 2005, the related papers have been indexed by some worldwide famous citation systems, such as EI (Engineering Index) and ISTP (Index to Scientific & Technical Proceedings). Moreover, the two major citation systems in China, CSSCI (Chinese Social Science Citation Index) and Chinese Core Journals have indexed 39 and 66 papers respectively, as listed in the left part of Table 2.

It can be concluded that the research on CDIO theory and its implementation in China has gradually drawn attention from academia and publishers.

Foundation Supports

From the collected data, the numbers of papers supported by foundations at various levels are listed in the right part of Table 2. Within the total of 512 papers, 229 papers have been supported by a foundation. This support indicates that CDIO theory is beginning to be emphasised at all levels of government, the institutes and the public to some extent. However, the majority of foundations are provincial or institutional and the national foundations play only a small part.

Table 2: Summary of papers indexed in citation systems and supported by foundations.

Citation System	Number of Papers	Foundation Level	Number of Papers
EI	35	National	31
ISTP	22	Provincial	87
CSSCI	39	Civic	12
Chinese Core Journals	66	Institutional	97
		Private	2

Top 15 High-productivity Authors and their Affiliations

From the data of the top 15 high-productivity authors and their affiliations, as shown in Table 3, the introducers of CDIO to China, the authors in Shantou University, are far ahead (50 papers - actually 36 papers, due to co-authorship). Central South University (12 papers) and Heilongjiang Institute of Science and Technology (12 papers) are next.

Among the 15 authors, only two authors come from universities in Project 985. In contrast, many authors from general universities and vocational institutes have a high productivity of CDIO research.

Table 3: Statistics of the affiliations of top 15 high-productivity authors.

Order	Author's Name	Number of Papers	Author's Affiliation
1	Xiong, Guangjing	13	Shantou University
2	Lu, Xiaohua	12	Shantou University
3	Shen, Minfen	8	Shantou University
4	Gu, Peihua	6	Shantou University
5	Wu, Ming	6	Shantou University
6	Hu, Zhigang	6	Central South University
7	Ren, Shengbing	6	Central South University
8	Qiao, Fu	6	Heilongjiang Institute of Science and Technology
9	Wang, Guoquan	6	Heilongjiang Institute of Science and Technology
10	Zhuang, Zhemin	5	Shantou University
11	Cha, Jianzhong	5	Beijing Jiaotong University
12	Wu, Yajuan	5	Northeast Petroleum University (previous Daqing Petroleum College)
13	Xu, Bing	4	Institute of Vocational Technology at Suzhou Industrial Park
14	Wang, Hongjun	4	Shijiazhuang Institute of Railway Technology
15	Wang, Gang	4	Shanghai Second Polytechnic University

CO-OCCURRENCE NETWORK ANALYSIS OF THE CDIO-RELATED KEYWORDS

In order to understand the focus of related authors, all the keywords in 512 papers were extracted and analysed. The frequency (number of occurrences) of each keyword was summarised so that the top 30 high-frequency keywords and their frequencies were determined, as listed in Table 4. Afterwards, the co-occurrence network of these 30 keywords was analysed and the co-occurrence diagram was drawn with a program written in the Java language, as depicted in Figure 2. In this keyword co-occurrence network, a node means a keyword and a line denotes that two keywords co-occur in one paper. The wider the line is, the more times these two keywords co-occur.

The keywords co-occurring with CDIO include, in descending order, *engineering education*, *pedagogical reform*, *pedagogical mode*, *engineering education mode* and *learning by doing*, *talent cultivation*, etc. It can be concluded that the majority of Chinese scholars have an understanding that CDIO belongs within the scope of engineering education. They consider CDIO as an approach or a model of pedagogical reform and have mastered the *learning by doing* essence of CDIO and its ultimate target of helping to cultivate practical talents.

Table 4: Top 30 high-frequency keywords and number of appearances.

Keywords	Times	Keywords	Times
CDIO	336	Course project	9
Engineering education	56	Education mode	8
Pedagogical reform	47	Innovation capability	7
Pedagogical mode	21	Integration	7
Reform	20	Higher vocation	6
Engineering education mode	18	Pedagogy	6
Talent cultivation	18	Data structure	6
Learning by doing	17	EIP-CDIO	5
Curricula	15	Engineering ability	5
Practical teaching	15	Quality of teaching	5
Curriculum reform	11	Embedded system	5
Cultivation mode	11	Soft capability	5
Project-based teaching	11	Practice	5
Higher engineering education	10	Project	5
Talent cultivation mode	10	CEC-CDIO	4

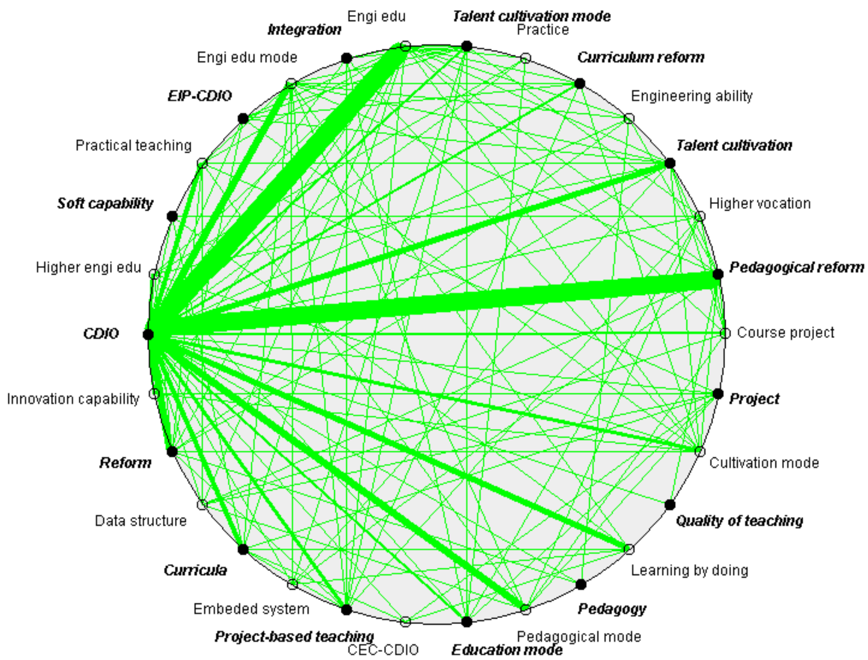

Figure 2: Co-occurrence network of top 30 high-frequency keywords.

CHINESE SCHOLARS' CONTRIBUTION TO CDIO: SHANTOU UNIVERSITY AS AN EXAMPLE

To have an overview of Chinese scholars' contribution to CDIO theory, the 36 papers published by the scholars at Shantou University were extracted. Their contribution is summarised by contribution category, as listed in the left part of Table 5, and by publication year, as shown in the right part of Table 5.

The scholars from Shantou University undertake CDIO research systematically. From *introduction*, *implementation*, *summary* and *innovation*, the number of papers is reasonably distributed in accordance with that in the *implementation* category. From the view of publication year, the numbers of published papers are increasing on the whole, but noting the outstanding value of 13 in 2008. Their major contribution can be inferred from three categories: *introduction*, *implementation* and *innovation*, depicted as follows (Table 5). The total number is greater than 36 because the categories overlap.

Table 5: Numbers of papers from Shantou University (by contribution category and publication year).

Category	Number of Papers	Publication Year	Number of Papers
Introduction	9	2005	1
Implementation	19	2006	3
Summary	5	2007	6
Innovation	5	2008	13
		2009	5
		2010	8

Shantou University began research on the CDIO model in 2005. Taking into account the situation in China, the College of Engineering took the lead in introducing CDIO theory to China. Also, they organise an academic conference periodically to summarise, discuss and give CDIO theory a big boost.

Shantou University has developed design-orientated and modularised CDIO syllabi. The College of Engineering at Shantou University has five specialties. In the reform process based on CDIO, students in each specialty were guided with a lifecycle that included well-planned conception, design, implementation and operation stages, and became more interested in the core courses and achieved a comprehensive and clear understanding of their specialty.

Shantou University proposed creating the EIP-CDIO (Ethics, Integrity, Professionalism - CDIO) model, to take account of the real situation in Chinese engineering education; EIP (Ethics, Integrity and Professionalism) is compatible with the ethos in Part II of the CDIO syllabus, which covers ethics, integrity, responsibility, etc. As an innovation of CDIO, EIP-CDIO emphasises professional ethics and integrity, integrates organically with conceive-design-implement-operate ideas, and aims to cultivate higher engineering professionals [9].

Moreover, the statistical data of published papers shows that Shantou University is leading CDIO development in China. For example, Figure 1 shows that the largest number of CDIO-related publications was in 2010, while Table 5 shows that Shantou University published the most papers in 2008. Therefore, by and large, Shantou University is outstripping other Chinese universities by about two years.

PROBLEM FINDING

Engineering education is the major channel promoting national economic development with qualified engineers in engineering or the business management field [10]. After more than 10 years of development, the validity and practicability of CDIO theory has been sufficiently proven globally in engineering education. In developing countries, if CDIO is positively introduced, adopted and innovated, the process of engineering education reform will be enhanced, while the development potential of science and technology will be increased.

In China, engineering education reform definitely will be successful, provided institutional scholars undertake active research and practice, the government provides support, and industry is positively involved. However, from the analysis in this research, some problems to be addressed with CDIO development in institutes, the government and industry, are as follows.

The majority of Chinese key universities have not yet paid enough attention to CDIO: From the statistical data, it can be seen that in the universities whose major support is from the nation such as those in Project 985 or Project 211, only a few scholars are concerned about CDIO so far. The main productivity as measured by publications was by the two national CDIO implementation groups led by Shantou University. From both the numbers of published papers by different groups of universities and the affiliations where the top 15 high-productivity authors come from, it must be admitted that the universities with major support by the nation do not attach importance to CDIO.

These key universities should take the burden of promoting engineering education reform in China, but they do so slowly or with a *wait and see* approach. If it is not because they have a low opinion of CDIO, and not because they feel a loss of face at key universities in following CDIO theory, and not because they worry that developing CDIO may degrade their academic rankings, then, the deep-rooted reason behind this phenomenon is worthy of the fullest consideration.

China's MOE does not adequately play a crucial role in CDIO adoption: From the successful experience of engineering education gained by some developed countries, such as the USA and Germany, government needs to play a decisive role in education. In China, among the 39 universities that MOE approved in two national CDIO implementation groups, only one newly emerging school in Zhejiang University (in Project 985) and eight universities in Project 211 joined in. Considering the financial support by government, just about 6% of papers get national-level foundation support. This shows that the relevant departments in government should place much more emphasis on CDIO development.

Chinese industry does not participate in CDIO implementation as early as it should: Since CDIO is an industry-orientated engineering education model, industry should understand the idea of CDIO in advance, make sense of the advantages of CDIO and co-operate with institutes to cultivate more qualified engineers. Industry is actually the ultimate beneficiary of the CDIO model, but unfortunately, from the history information and news in China's CDIO official Web site, no remarkable stories of industrial involvement can be found yet.

CONCLUSIONS AND SUGGESTIONS

For Institutes: Conceive-Design-Implement-Operate is a framework of educational thoughts and approaches guiding engineering education reform [8][11]. It has distilled and developed the ethos of engineering education reform in European and American countries for over 20 years. With more than 50 collaborating institutions in over 25 countries worldwide, the CDIO Initiative is expanding constantly [12]. In order to carry out the implementation of CDIO, universities, especially those with major support from nations, should: 1) positively study and publicise the ethos of CDIO for major issues; 2) implement the ideas of CDIO in specific course design and experiments: improve the status of engineering education, which requires earnest groundwork; 3) positively co-operate with the CDIO leading institutes; enhance national and international co-operation; promote engineering education reform; 4) co-operate with industry to cultivate more industry-orientated practical skills.

For Industry: There is no doubt that CDIO is an industry-orientated framework. It satisfies the general needs of modern engineering education, has a brilliant perspective and great popularisation value in promoting national industry. Therefore, as the ultimate beneficiary of CDIO theory, industry should: 1) positively co-operate with institutes and construct or refine the platform of institute-industry interoperation for cultivating practical skills [13]; 2) refer to the objectives of CDIO regarding adjusting the requirements of human resources and helping institutes implement the CDIO ethos; 3) financially support research of CDIO-related projects.

For Government: Conceive-Design-Implement-Operate will pass through an incremental development process and need the regulation, guidance and support of the government. In any case, CDIO offers a rare opportunity that should be grasped tightly. Whether CDIO can help promote engineering education reform depends on the cognition, determination and action of the government.

Therefore, the government should: 1) apprehend the essence and function of CDIO in the engineering education field as soon as possible, and play the key role of guiding and co-ordinating the development of CDIO. If CDIO is really not worthy of following, the government should encourage and support the scholars of this nation to create a theory system similar or superior to CDIO because the current engineering education reform in China does need a scientific and feasible education reform framework like CDIO. If CDIO is worthy of following, then why wait? 2) especially encourage some superior universities majoring in science and engineering to explore new approaches to engineering education reform and further financially support research on engineering education; 3) co-ordinate the relationship between institutes and industry, speed up the pace of introducing and adopting CDIO, make CDIO an incisive function in cultivating more and more practical engineering professionals.

REFERENCES

1. Shi, M., American higher education reform orienting the 21st century. *China University Teaching*, **10**, 38-40 (2002) (in Chinese).
2. Li, Z. and Lin, F., Exploration into American higher engineering education reform. *Researches in Higher Educ. of Engng.*, **2**, 31-35 (2008) (in Chinese).
3. Yu, S., Wang, S. and Li, M., Survey report of the certification, reform, and development of German engineering education. *Researches in Higher Educ. of Engng.*, **1**, 57-59, 64 (2006) (in Chinese).
4. Jiang, S. and Wang, P., ECUK: An engine for change of engineering education. *Researches in Higher Educ. of Engng.*, **1**, 16-23, 46 (2007) (in Chinese).
5. Education Committee of Chinese Academy of Engineering. Exploring the roadmap of China's engineering education: reform and development of engineering education in new situations (summary of high-level forum). *Researches in Higher Educ. of Engng.*, **6**, 43-47 (2007) (in Chinese).
6. Xu, X., The approach and practice of software industry-oriented education in China. *J. of Harbin Institute of Technology (new series)* 12, SUPPL, 1-3 (2006).
7. Crawley, E.F., The CDIO Syllabus: A Statement of Goals for Undergraduate Engineering Education. MIT CDIO Report #1, Massachusetts Institute of Technology (2001).
8. Crawley, E.F., Malmqvist J., Lucas W.A. and Brodeur, D.R., The CDIO syllabus v2.0: an updated statement of goals for engineering education. *Proc. 7th Inter. CDIO Conf.*, Technical University of Denmark, Copenhagen (2011), http://publications.lib.chalmers.se/records/fulltext/local_143186.pdf.

9. Gu, P., Lu, X., Xiong, G., Li, S. and Shen, M., The development of design directed engineering curriculum based on the CDIO framework. *World Transaction on Engng. and Technol. Educ.*, 5, **2** , 267-270 (2006).
10. Zhu, G., Discussion of the problems and solutions of Chinese engineering education. *Researches in Higher Educ. of Engng.*, **4**, 1-6 (1998) (in Chinese).
11. Yellowley, I. and Gu, P., Design directed engineering education. *J. of Engng. Design and Innovation*, 1, **1**, 1-7 (2005).
12. Worldwide CDIO Initiative. The CDIO Standards (2004), 4 May 2011, http://www.cdio.org/implementing-cdio-your-institution/standards.
13. Wang, Y, Qi, Z., Li, Z. and Zhang, L., Institute-industry interoperation model: an industry-oriented engineering education strategy in China. *Asia Pacific Educ. Review*, 12, **4**, 665-674 (2011).