# AC 2012-5526: CULTIVATING T-SHAPED ENGINEERS FOR 21ST CENTURY: EXPERIENCES IN CHINA

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# Cultivating T-shaped Engineers for 21st Century: Experiences in China


## Abstract

The dynamic society calls for changes on engineering and its workforces; and thus triggers a transformation on current engineering education. This paper begins with concerns on social demanding and then introduces a new workforce called T-shaped engineer embraced by the academic and industrial field. This new profile is generally defined as broadly learning and weaving across disciplines (top of the T) and going deeply into understanding engineering concepts (vertical branch of the T).

Though T-shaped talents are much better preparing for the 21st century, this new profile can hardly be created by traditional education. The paper analyzes the situation of China specifically, indicating an ill-structured model T—narrow vertical bar, shallow horizontal line and with its whole T not solid enough.

In response, China is pacing up to evolve in a number of ways that qualify graduates and build a stronger T, among which the "Advanced Honor Class of Engineering Education" (ACEE) launched by Zhejiang University (Zhejiang Province, China) serves as an example on how to build T-shaped engineers. Based on the case, ACEE presents a feasible way on how to build T-shaped engineers, including solidify the professional foundation, concentrate on engineering management, emphasis on engineering design and practice, which is worthy promotion nationally and even abroad.



**Key Words:** T-shaped Engineers Engineering Education Chinese Situation


## I. Introduction

Engineering education is always confronted by new challenges. It is widely observed that we are living in an era of accelerating change and increasingly global society, driven by the growth of new knowledge, together with the rapidly evolving information and communication technologies (Grasso et al., 2010). The dynamic challenges and exponential opportunities in the 21st century call for a shift in our thinking on engineering practice and education.

The exciting future of engineering is "beyond technological labels" (e.g., mechanical engineer, electrical engineer, and chemical engineer), which represents for a "more cross-disciplinary, whole-systems approach to engineering that "emphasizes contextualized

problem formulation, the ability to lead team-centered projects, the skill to communicate across disciplines, and the desire for life-long learning of the engineering craft in a rapidly changing world" (Grasso et al., 2010).

The changing nature of engineering will inevitably require corresponding engineering workforces, who are "cathedral builders", rather than" the equivalent of bricklayers" (Irving, 1998); who are not only "comprehensive problem solvers", but "problem definers"(Grasso et al., 2010); who have a basic knowledge of adjacent and connecting fields so as to readily adapt to address the novel, complex problems that they will encounter, leading multidisciplinary teams of professionals and fostering innovation.

The presented changes force a timely and adequate reform to current engineering education. This paper introduces a new workforce called T-shaped engineer embraced by the academic and industrial field. Though T-shaped talents are much better prepared for the 21st century, this new profile can hardly be created by traditional education. The research then analyzes the situation of China, indicating an ill-structured model T. In response, China is pacing up to evolve in a number of ways that qualify graduates and build a stronger T. The "Advanced Honor Class of Engineering Education" launched by Zhejiang University will serve as one of the best practices in Chinese engineering education. Based on the case, it presents a feasible way on how to build T-shaped engineers, worthy of promotion nationally and even internationally.

## II. A Demand for New Workforces: T-shaped Engineers

In recent engineering education discourse, there is vast discussion of T-shaped engineers to provide a metaphor for describing an ideal engineer: Broadly learning and weaving across disciplines (top of the T) and going deeply into understanding engineering concepts (vertical branch of the T) (Oskam, 2009).

The concept of T-shaped engineers has not been widely spread and accepted until recent years, with its origins and arguments in other areas, such as Information Technology (IT) and knowledge-intensive business services. The earliest known use of the phrase T-shaped people in print was in a 1991 London newspaper editorial. David Guest, responding to a report on jobs in computing, wrote: "This type of rounded personality is also sought in other branches of the same theory, which prizes individuals known as T-shaped People: These are a variation on Renaissance Man, equally comfortable with information systems, modern management techniques and the 12-tone scale"(Guest, 1991).Other researchers also use the terms, such as "T-Professional", "Generalizing Specialist"(Appelo, 2010), "Hybrids"(Palmer, 1990), "Versatilist"(Diane, 2005). Nevertheless, these new profiles can hardly be created by traditional education.

Currently, the growing gap between engineering practice, education and research is a cause for concern. One of the keys to equip qualified engineering students (e.g. T-shaped talents) is

to help them learn about engineering in context: Giving adequate opportunities for both deepening and widening their knowledge base and for learning all the necessary skills (Oskam, 2009). Specifically, there is a call for sweeping structural and cultural changes in engineering education, including: a shift from disciplinary thinking to interdisciplinary approaches; increased development of teaming skills; greater consideration of the social, environmental, business, and political context of engineering; improved student capacity for life-long learning; and emphasis on engineering practice and design throughout the curriculum (Kerns, 2002).

## III. The Situation of Chinese Engineering Education

China has been widely noticed by the whole world for its miracle of booming economy, recognized as a big manufacturing kingdom. This country has the largest scale of engineering talents, with approximately 42 million people trained in science and technology, 42.9% of which having bachelor degree or above(Zhong et al., 2010). Due to relatively greater numbers and far lower wage structures, China' engineers are relatively popular in global market contemporarily.

Despite that, China is pacing up on its way to economic transformation, moving from a manufacturing economy to a value-added, service-oriented economy. To this end, instead of quantity of talents, the quality of future workforce should be paid more attention to. High-qualified engineers, characterized by deep problem-solving skills in one area and broad intellectual span, are in shortage. However, current approach to engineering education does not sufficiently train T-shaped engineers to adapt to the needs of future. Among the many concerns the three main problems exist in Engineering Education in China are the following: As a metaphor, the whole T is neither well-structured nor solid enough.

- **Vertical Bar of the T is Narrow: Weak at Professional Foundation**

Although we begin the letter T with the top horizontal line, the priority should undoubtedly be placed on the vertical bar, for T can hardly stand stably without a strong foundation. China has always focused on professional education since the era of planning economy, manufacturing a mass of workforces with solid professional foundation. However, with the advent of information explosion there emerge countless new fields of knowledge and a multitude of specialized subjects, so engineering education in China steps into a dilemma: Over-specialization, which entails splitting up the disciplines into different levels of subjects. According to China's national classification and code of disciplines, there are 21 first-degree subjects, 200 second-degree subjects, and 526 third-degree subjects in the discipline of engineering and technology science.

- **Horizontal Line of the T is Shallow: Lack of Interdisciplinary Integrity**

In China, discipline-based education tends to cultivate specialists who are extremely deep and

confined to one aspect, rather than T-shaped professions, who are, on the contrary, knowledgeable, comprehensive or interdisciplinary and thus well-equipped to both a first job and a final career. In some colleges, the engineering curriculum is limited, without consideration for the integrity of different disciplines; the so-called general education turns out to be some superficial electives, which fail to attract students and faculty as well.

- **The Whole T is not Solid Enough: Restrained Open Innovation**

Education patterns in Chinese colleges tend to cultivate talent experts in studying the world as it is rather than creating the world that doesn't yet exist: the latter truly represents engineers. The existing curriculum focuses on theories and text with pre-set results and memorizing facts, ignoring deep approaches to learning, such as practice-oriented, open-innovated and design-based ones. And thus, students fail to be attracted by engineering education and lack crucial qualities and abilities such as strategic thinking, critical thinking and innovation for lifelong learning and long-term development.

Recognizing problems is the first step to reform. In response, the Chinese Ministry of Education (CME) proposed the "Excellent Engineers Training Program" in 2010. This large-scale engineering education reform is aiming to train a large number of outstanding engineers who have strong creative ability and could meet economic and social development demands, providing a solid intellectual support for the economic restructure and national innovation. Until now, the CME has supported 194 universities and colleges to run the trials. China's engineering education is on its way to break the tradition and create another miracle, compatible with its economic situation and international competition.

## IV. A Case in China: "Advanced Honor Class of Engineering Education"

In an attempt to produce T-shaped professionals for the 21st century, colleges in China have offered a set of nontraditional curricula and pedagogic methods, among which the "Advanced Honor Class of Engineering Education" (ACEE) launched by Zhejiang University (Zhejiang Province, China) serves as an example on how to cultivate T-shaped engineers.

ACEE, one of the honor classes in Zhejiang University, has been established since 1994. As an experimental undergraduate training program for advanced engineering education, it lays emphasis on basic knowledge, designing and creativity, aiming to provide a cross-disciplinary learning environment for the top students and cultivate them into the future leadership in the engineering field.

### A. Training Plan

Every year, the honor class selects only 40 (60 before 2009) freshmen from the departments of science and engineering based on the students' academic performance and comprehensive quality as well. After unified general education in the first year, those students will be given

extra engineering training besides their major studies for the next three years. According to ACEE training plan (Table 1), students who obtain full 28 credits are qualified to get a certificate from ACEE.

Table1. Training Plan of ACEE in Zhejiang University (Zou et al., 2010)

| Items | Training Plan |
|---|---|
| Objective | Innovative Engineering Talent |
| Request | Sophomores in background of science and engineering |
| category | Minor class |
| Length | Three years |
| Credit | 28=17 compulsory credits + 7 elective credits + 4 practice credits |
| Outcome | Certificate of "Advanced Honor Class of Engineering Education" |

## B. Curriculum Design

Curricula in ACEE are designed systematically and scientifically by experts in engineering education from Research Center of Science, Technology and Policy (RCSTRP) in Zhejiang University and practitioners in industry. Four modules are covered, including Engineering Foundation Module, Engineering Design Module, Engineering Management Module and Engineering Practice Module. Students ought to learn 2 or 3 courses to fulfill the regulated credits or take part in engineering design and practice activities instead. The exact teaching program is listed as follows (Table 2) (Zou et al., 2010).

Table2. Teaching Program on ACEE in Zhejiang University

| Modules | Courses | Credits | Schedule | | | Remark |
|---|---|---|---|---|---|---|
| | | | Second Year | Third Year | Fourth Year | |
| **Engineering Foundation Module** | Introduction to Engineering | 2 | √ | | | Compulsory |
| | The Principle of Engineering(I) | 3 | √ | | | Elective |
| | The Principle of Engineering(II) | 3 | | √ | | Elective |
| | Mathematics Modeling | 4.5 | √ | | | Compulsory |
| | Systems Science and Engineering | 2 | √ | | | Compulsory |
| **Engineering Design Module** | Fundamentals of Data Structure | 2.5 | √ | | | Choose One |
| | Computer Graphics | 3 | | √ | | |
| | Design Thinking and Expression | 3 | √ | | | Compulsory |
| | Embedded System | 2 | | √ | | Compulsory |
| | Computer Aided Innovation | 2 | | √ | | Compulsory |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Engineering Management Module** | Leadership Development | 1.5 | | √ | | Choose One |
| | Production and Operation Management | 2 | | | √ | |
| | Project Management | 2 | | | √ | |
| | Entrepreneurial Management | 1.5 | | | √ | |
| | Technological Management | 1.5 | | √ | | Compulsory |
| **Engineering Practice Module** | Engineering Research and Practice | 2 | | | | Practice |
| | Integration and Innovation Design | 2 | Any Semester | | | Practice(Choose One) |
| | Electronic System Comprehensive Design | 2 | Short Term | | | |

### C. Analysis: How to build a stronger T

Zhejiang University is one of the earliest colleges in China, which carries out general education and attempt to build simple T-shaped abilities successfully (Figure 1). In particular, before choosing their final majors in the second year, students in Zhejiang University are fostered in eight general directions, namely, nature science, engineering, information technology, practical biology science, biological medicine, literature, sociology and creative technology, and take common courses and basic courses in general directions for the first year, forming the top line of model T.

But as the dilemmas mentioned before, the training plan of "general education plus professional education" is far from enough to cultivate potential leaders with high quality and multicultural horizon and build the university itself into an institution on a par with the first-class university in the world. How to build a stronger T? ACEE presents a feasible way.

#### a. Solidify the Professional Foundation

The module of engineering foundation is well-designed, flexible for students from different directions, acting as complement to the basic of engineering. For example, the existing course *The Principle of Engineering (I)* mainly teaches the principle of mechanics, including hydromechanics, engineering thermodynamics, heat, mass and momentum transfer; while *The Principle of Engineering (II)* is about electromagnetic field, electromagnetic wave, and circuit device as well. Students who have already taken specialized courses in the former field are only required to attend the latter course, and vice versa. *The Principle of Engineering (III)* on materials will be established later on.

#### b. Concentrate on Engineering Management

Considering that general courses tend to be massive and decentralized, ACEE exploits the

*Leadership Development Plan (LDP),* concentrating on creating engineering leaders who can deal with novel, complex projects with team members and even set up their own businesses. As a part of the plan, engineering management module invites leading scholars in their fields teaching attractive courses (such as *Leadership Development*, *Entrepreneurial Management* and etc.), together with practice chances (to be discussed below) for the students to apply the acquired knowledge.

### c. Emphasis on Engineering Design and Practice

ACEE positions itself as an integrated application platform, making every chance for students to enjoy design and practice. Students from different discipline backgrounds are encouraged to accomplish coursework in groups and join in domestic and overseas competitions, such as International Mathematical Modeling Competition, National Undergraduates' Innovation Experimental Program, Electronic Design Contest, Mechanical Design Contest, Venture Competition, and Student Research Training Program (SRTP) in Zhejiang University.

All these above have successfully rebuilt T-shaped output to be a much better-structured and stronger one (Figure 1).

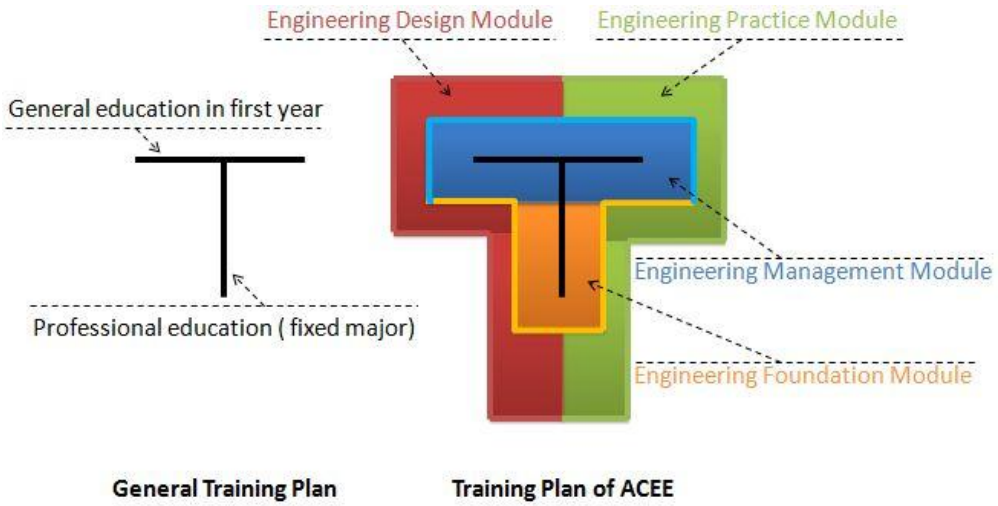


Figure1. A Comparison between General Training Plan and ACEE

## D. Output

847 students have graduated from ACEE since 1994, and 120 students (Class of 2008/2009/2010) are under the training of ACEE. According to a tracking survey, this extra engineering training plan has successfully provided students with compound skills and abilities needed to solve ill-structured and undefined issues faced in 21st century.

Students in ACEE individually and more often working in groups have made brilliant achievements in academic activities and various contests. About 3 students in ACEE win Chu Kochen Scholarship (highest prize in Zhejiang University, with only 12 undergraduates

awarded) every year. They also do excellent jobs in various competitions following the instructions and guidance of advisors. After graduation, most of the students have gone for further study (two thirds at world-class universities) and the rest have taken high-salaried jobs or started businesses. Take graduate students (Class of 2007) for example: 60 joined ACEE in 2008 (the second year) and 55 of them finished their study and graduated in 2011. Among all the graduate students, 53 of them take further study in top universities domestically and abroad (17 and 36 respectively), and one student set up his own business. (See Table 3)

Table3. Output: Graduate Students (Class of 2007)

| Option | Number | Went For | Country |
|---|---|---|---|
| Further Study | 14 | Zhejiang University(ZJU) | China |
| | 1 | Southeast University(SEU) | China |
| | 1 | Shanghai Jiaotong University(SJTU) | China |
| | 1 | Peking University(PKU) | China |
| | 3 | Hong Kong University Of Science And Technology(HKST) | HK, China |
| | 1 | Hong Kong Polytechnic University(HKPU) | HK, China |
| | 2 | The Chinese University Of Hong Kong(CUHK) | HK, China |
| | 1 | University of Delaware | U.S. |
| | 1 | University of Illinois at Urbana-Champaign(UIUC) | U.S. |
| | 2 | University of California at Los Angeles(UCLA) | U.S. |
| | 1 | University of Wisconsin-Madison | U.S. |
| | 1 | Cornell University | U.S. |
| | 1 | Yale University | U.S. |
| | 1 | University Of Central Florida | U.S. |
| | 2 | University of California DAVIS(UC DAVIS) | U.S. |
| | 1 | Georgia Institute Of Technology（GIT） | U.S. |
| | 1 | New York University(NYU) | U.S. |
| | 2 | Johns Hopkins University(JHU) | U.S. |
| | 1 | University of Maryland | U.S. |
| | 1 | Columbia University | U.S. |
| | 1 | California Institute of Technology | U.S. |
| | 1 | University of Virginia | U.S. |
| | 1 | Duke University | U.S. |
| | 1 | Massachusetts Institute of Technology (MIT) | U.S. |
| | 1 | Texas A&M University (TAMU) | U.S. |
| | 1 | Tulane University | U.S. |
| | 1 | Queen's University | Canada |
| | 1 | Toronto University | Canada |
| | 1 | Technical University of Eindhoven | Holland |
| | 2 | University of New South Wales(NSWU) | Australia |
| Work | 1 | Work for Singapore Technologies Engineering | Singapore |
| | 1 | Set up own business | China |

## V. Conclusion

The social development accelerates the demands for well-rounded engineers who bear deep technical skills coupled with profound knowledge in areas such as business, management, communication and even entrepreneurship, embraced as T-shaped engineer by the academic and industrial field. Preparing for an economic transition, China ought to cultivate a large number of T-shaped talents so as to stay competitive and create greater improvements in the future. However, engineering curricula and teaching methods often fail to be well aligned with these goals in China and even worldwide. The "Advanced Honor Class of Engineering Education" launched by Zhejiang University presents a feasible way on how to build stronger T-shaped engineers with solid professional foundation, centralized training on engineering management and adequate chances on engineering design and practice.

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