A Decade’s Experience in Reforming Undergraduate Computer Science Education in China

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ABSTRACT
In the past decade, the educators of China have spent substantially efforts in reforming China’s computer science (CS) undergraduate education to better prepare students for their future careers, industrially or academically and achieved many successes. In this paper, we review these efforts from three perspectives: (1) Two representative nationwide CS education reform initiatives in China; (2) Chinese CS educators’ involvement in two international CS education reform project; and (3) experiences of undergraduate CS education reform in two top-tier universities in China.

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1 INTRODUCTION
The second decade of the twenty-first century witnesses the great success of computer science technologies. Almost everyone uses computers as part of her/his daily life. In 2010, an article published at SIGCSE 2010 [8] gave an overview on the undergraduate computer science education in China. Since then, CS educators in China have been spending substantial efforts to continuously reform the undergraduate CS education in China. Their goal is to keep up with the fast development of the computer science discipline and the more stringent requirements of computer related job opportunities so that students in an undergraduate CS program can be better prepared for their future careers.

Through the hard work and close collaboration of CS educators from both universities and industries, the undergraduate CS education in China has achieved substantial successes. Computer science and technology (i.e., the name of computer science major in China) has become the most popular major in China. A vast majority of CS major undergraduates are able to find high-paying jobs at technology companies all around the world (e.g., Alibaba, Google, and Microsoft) when they graduate. Students who choose to pursue master or doctor degrees in computer sciences receive substantial more opportunities from top-tier universities, both domestic and international, than the first decade of this century.

The goal of this paper is to review these reforming efforts of CS educators of China in the past decade. Although there have been several articles and presentations introducing these efforts, many of them were published in domestic, non-English venues. The authors of this paper are active voices in both Chinese and international CS education community. As such, we want to take this paper as an opportunity to present the experience of Chinese CS educators to the global computer science education community.

This paper does not aim to be comprehensive. Instead, we focus on representative reforming efforts in the following three perspective:

China’s nationwide undergraduate CS education reforming initiatives (§2). We focus on introducing two such initiatives: the talent training plan [6] and the 101 plan [7]. The Ministry of Education (MoE) of China starts the talent training plan in 2009. The goal of this plan is to cultivate top students who plan to pursue a career of research after undergraduate study. The plan is not limited to computer science, but for all STEM majors. In contrast, the 101 plan, which is launched by China MoE at the end of 2021, is an initiative specifically focusing on reforming undergraduate CS education to better equip students with necessary knowledge and skills for their future careers.

Chinese CS educators’ participation in international undergraduate CS education reforming projects (§3). We focus on the roles of Chinese CS educators in two such projects: the ACM/IEEE-CS CC2020 project and the ACM/IEEE-CS/AAAI CS2023 project. CC2020 aims to provide general guidelines for modern, global undergraduate education in the general computing field, including computer science, computer engineering, information systems and etc. Its key
practice is to move away from the traditional knowledge-based learning model and develop a conceptual competency framework for undergraduate computing education, emphasizing on the integration of knowledge, skills and professional disposition, without providing any specific curricula. The CC2020 task force releases its final report in early 2021. In contrast, CS2023 is an ongoing project starting from May 2021. It aims to design specific curricula for the undergraduate computer science education for the next five to eight years. To allow its adoption with ease, this curricula provides both an updated knowledge model and a competency model. CS educators from China play important roles in both projects by (1) serving as steering committee members, task force members, and external contributors, (2) publicizing them in China, and (3) practice building competency for students during undergraduate teaching.

**Practice experiences in top-tier universities in China** ($§4$). Under the umbrella of nationwide reforming initiatives and the impact of international reforming projects, universities in China are actively exploring how to provide students higher-quality undergraduate computer science education. We focus on Shanghai Jiao Tong University and Xiamen University, two top-tier universities in China that have a strong computer science program, and introduce their various experiences in how they build students’ knowledge, skills as well as professional disposition in computer science.

## 2 NATIONALWIDE CS EDUCATION REFORM INITIATIVES

The most representative explorations on computer science education in China are the ”Top-notch plan” and the “101 plan”. This section will describe how these two plans were implemented and what results were achieved.

### 2.1 The “Talent Training plan”

In 2009, the Ministry of Education launched the “Talent training plan” 1.0. Computer science is one of the first five top-notch disciplines selected. Along with the ten-year plan, 98% of the 6,647 graduates continued to study for postgraduates, and 32% entered the world’s top 50 disciplines for further study, showing the potential to become future scientific leaders. In 2020, the second version of this plan has been launched, which plans to train tens of thousands of top students in basic disciplines from 60 colleges and universities in the next 10 years. [1] The development of the talent training plan 1.0 to 2.0 is to expand the scope of disciplines horizontally, from pure science to comprehensive arts and sciences.

This plan does not regard students’ grades during schooling as the only standard but pays attention to the combination of written examinations, interviews, and expert recommendations. Thus, it can provide opportunities to some “partial talents”, “weird talents” and students from non-famous schools to have a better education. In addition, this plan encourages the establishment of high-level tutor groups to jointly guide students. According to the characteristics of different disciplines, this plan proposes to formulate corresponding support policies to get rid of the evaluation system of “only papers”. For the training of top-notch innovative students in engineering, it is recommended to unite scientific research intuitions and enterprises by the sharing of guidance and equipment resources to cultivate world-class scientific and technological talents.

### 2.2 The “101 plan”

In December 2021, based on the proposal of Professor John Hopcroft and the overall deployment of Minister Huai Jinpeng, the Ministry of Education in China decided to implement a pilot work plan for undergraduate education and teaching reform in the computer field (referred to as “101 Plan”).

The goal of the “101 plan” is to launch a batch of famous courses, teachers, and textbooks in the computer field within two years, driving the overall improvement of the quality of personnel training in colleges and universities. To be specific, the main tasks of this plan include:

- **Core curriculum system construction**: 12 excellent courses are selected and concentrated to be built in this plan. They will form a complete core computer course system, including the construction of the course knowledge points, online resources, and practice platforms.
- **Core teaching material system construction**: A batch of world-class, Chinese characteristics, and 101-style excellent core textbooks are expected to be built to form a computer core textbook system.
- **Classroom teaching effect improvement**: Through on-site lectures and seminars, a measurable and visible improvement in the quality of classroom teaching is expected. A group of excellent teachers is trained.

The “101 Plan” working group is mainly led by 33 domestic colleges and universities under the leadership of Peking University, selects more than 300 excellent teachers to form the secretariat, curriculum construction group and classroom improvement group, and finally produces 12 core courses. The 12 core courses in computer science are algorithm design and analysis, discrete mathematics, introduction to artificial intelligence, data structure, introduction to the computer system, introduction to computer science, software engineering,
operating system, fundamentals of compiling, computer network, database system, and computer organization.

3 ENGAGEMENT IN INTERNATIONAL REFORMING PROJECTS

In additional to nationwide initiatives to evolve the computer science undergraduate education, Chinese educators also actively engage in international computer science curriculum building projects. In this section, we briefly review the activities of Chinese educators in two representative projects: CC2020 and CS2023.

3.1 CC2020

The Computing Curriculum 2020 (CC2020) project is an initiative launched jointly by ACM and IEEE-CS to provide modern, global guidance in undergraduate academic programs in computing, ranging from computer engineering, computer science, information systems, information technology, to software engineering with data science. To this end, a task force of fifty people from twenty countries, with a fifteen-member steering committee carrying the main operational responsibilities, is assembled.

Compared with its predecessor CC2005, the key proposal in CC2020 is to move from a knowledge-based learning model to the competency-based learning model and develops a competency framework. Specifically, competency is defined as the integration of knowledge (i.e., know-what), skills (i.e., know-how) and professional dispositions (i.e., know-why). The CC2020 report is officially published in early 2021 and has been endorsed by over twenty computing organizations.

Chinese educators’ involvement in CC2020. Chinese educators actively engage in the CC2020 task force in both personal and organizational capacities. For example, five Chinese educators are formal members of the CC2020 task force (i.e., one steering committee member and four regular members). Two of them are co-authors of this article. ACM China, ACM SIGCSE China, and China Computer Federation (CCF) all provide their endorsement to the CC2020 report.

After the publication of the CC2020 report, many Chinese educators also actively publicize the report in China and follow the guidelines of the report to conduct computer science curriculum practice at universities, with a focus on building the competency of undergraduate students. For example, the Chinese members of the task force translate the CC2020 report into Chinese and publish it []. They also work with other Chinese educators to organize forums and panels at CNCC and TURC, two of the largest computer science conferences in China []. During these venues, multiple educators share their experiences and lessons in building students’ competency in different areas of computer science (e.g., high-performance computing []).

3.2 CS2023

In May 2021, ACM, IEEE-CS and AAAI jointly initialize the CS2023 project. Different from CC2020, which focuses on building a competency framework for the general computing discipline and does not provide any specific curriculum, CS2023 focuses on designing specific curricula for global undergraduate computer science education for the next five to eight years. To this end, the CS2023 task force is assembled with 17 steering committee members from the world. Each member is a representative of ACM, IEEE-CS or AAAI, and chairs a subcommittee of four to six members to lead the curriculum design of one specific knowledge area.

Instead of completely switching to the competency-based model as did in CC2020, CS2023 embraces both the knowledge-based model and the competency-based model. Specifically, CS2023 will produce an updated knowledge model that reflects the recent progress and trend of computer science, and also incorporate a competency model to promote the importance of computer science undergraduate developing professional dispositions. In addition, CS2023 will also maintain the consistency between both models to provide a cohesive bridge between them. The rationale behind this methodology is to allow global computer science educators to adopt the CS2023 curriculum with ease while the community continues to explore the feasibility and benefits to build students’ professional dispositions.

Chinese educators’ involvement in CS2023. Motivated by the success of CC2020, computer science educators in China continues to actively engage in the CS2023 project. Specifically, one educator joins the steering committee and chairs the system fundamentals (SF) subcommittee. Two educators join the SF subcommittee as task force members and several others contribute to the project by means of reviewing the curriculum, providing feedback and experiences on the knowledge and competency model, and publicize the CS2023 projects at national computer science conferences and journals.

Among these contributors, three of them (also co-authors of this article) have also been exploring how to integrate competency building into their teaching in introductory courses of computer networking, Internet of things (IoT) and cybersecurity since fall 2021. Specifically, they redesign their lectures to cover both classic and emerging knowledge in these areas. In order to build students’ professional dispositions in using the knowledge and skills of these areas to solve real-world computer science problems, they also design programming assignments and class projects that mimic tasks of industry
employees and graduate-level research topics with an appropriate level of difficulty. In the feedback from students, they claim that what they learned from these courses is very helpful for their future interns, graduate studies and job hunting. One downside, though, is that the workload of these courses are substantially heavier than before. As such, one important next step is to achieve a better tradeoff between the benefits of competency building and course workload.

4 PRACTICE EXPERIENCES OF UNIVERSITIES

This section selects two top-tier universities in China as case studies to show the Chinese evolution of computer science education. Shanghai Jiao Tong University participates both in the “Talent training plan” and the “101 plan”. Another selection, Xiamen University, did not participate in either plan but has explored its unique education scheme as an active follower.

4.1 Major and Curriculum Settings

4.2 Explorations Following the “Talent training plan”

a) Zhiyuan Honor Plan

Shanghai Jiao Tong University launched the “Zhiyuan Honor Plan” in 2017. This plan is consistent with the “Talent training plan” with the characteristics of Shanghai Jiao Tong University. The “Zhiyuan Honor Plan” selected the top 10% outstanding students in basic disciplines to create a growth system of “future academic masters” that is in line with the world, where computer science is also selected as one of the disciplines. This plan has won the first national excellent in the ten-year evaluation of the Ministry of Education’s “Top-level Student Training Program for Basic Subjects”.

The program starts with cutting-edge experimental courses. It can help to initiate academic interest and build scholarly awareness among students. The program also frequently organizes in-depth academic discussions and encourages interdisciplinary cooperation. The Zhiyuan Innovation Research Center (ZIRC) is built to support undergraduates to develop scientific research and practice capabilities through such discussions and cooperation. Well-known scholars are gathered relying on this platform to build academic bridges for teachers and students to inspire innovative thinking and promote each other.

So far, 59 projects have been approved in this program. Some project research results have been published in top-tier academic journals or conferences such as Nature Photonics and Science Advances, including 17 first-authored papers, 2 corresponding authored papers and 20 cooperative papers. They have won 15 scientific and technological awards and applied for three patents. In 2018, the project “Efficient Interface Evaporation Device and Seawater Desalination” led by students of grade 2014 won the highest award in the U21 Global Innovation Challenge for the first time on behalf of Shanghai Jiao Tong University. In 2021, the question “Will the periodic table of elements be complete?” proposed by students of grade 2018 was selected in 125 scientific questions of Science (version 2.0) from scholars around the world. The graduation rate of participating students is 96%, and the direct doctoral rate is 70% [6].

b) IEEE pilot class

The IEEE pilot class is set up as another exploration of competency education. This class covers four professional directions in the electronic information area: computer science and technology, information engineering, automation, and information security. This class follows the tutor, direction, membership, and participation systems. To be specific, the IEEE senior/ordinary members and senior professors will serve as tutors in this class. Students can dynamically select interested directions and receive flexible training plans. They will all join IEEE student membership and participate in relevant academic activities and subject competitions under the leadership of their tutors.

The college provides a wealth of overseas study opportunities for the students of the IEEE pilot class. It regularly invites Turing Award winners, Nobel Prize winners, Fields Medal winners, and so on to the school to conduct in-depth exchanges with students. That will greatly help to broaden students’ international horizons, improve professional quality, and cultivate academic pursuits. According to the statistics of the past three years, 85% of the students in the IEEE pilot class went to Yale University, Columbia University, Cornell University, and other top-tier universities to continue their studies after graduation, and the rest of them went to well-known companies to work [3].

c) ACM class

The ACM class is established by professor Yu Yong in 2002. The name comes from the Association of Computing Machinery, an international computer organization for science education. This also means that the goal set up by the ACM class at the beginning is to train computer scientists. Within ten years, the students in the ACM class won the “Triple Crown” of the Global ACM Contest (an International Collegiate Programming Contest).

The ACM class has adopted a series of educational explorations. First, the class focuses on the development of a "thought-method-practice" system, which cultivates students’ ambition and self-learning ability. A research-based teaching model and curriculum system are correspondingly built.
Second, the class implements the “laboratory-classroom-society” training mechanism in a multi-level practice environment, which cultivates students’ comprehensive abilities in research, practice, coordination, and communication. Third, the class builds an elimination system to stimulate students’ enthusiasm and initiative in learning. Fourth, the class devotes to cooperating with internationally renowned companies (Microsoft, IBM, INTEL, Google) to carry out comprehensive school-enterprise cooperation.

Under the elite education in ACM class, some outstanding graduates have founded well-known enterprises, such as 4Paradigm, Liulishuo, Senyi Intelligence, Yitu Technology, etc. These enterprises are distributed in multiple directions of artificial intelligence and blockchain and thus have penetrated into all aspects of social services. At present, the overall valuation of these companies has reached tens of billions of yuan [4].

### 4.3 Explorations Following the “101 plan”

Shanghai Jiaotong University specifically participated in the construction of 9 core courses in the “101 plan”, among which the ”Data Structure” course was led by Professor Yu Yong. The virtual teaching and research section of the data structure course led by Prof. Yu was selected for the pilot list. Relying on this platform, the teaching effects will be further strengthened. High-quality resources could be jointly shared to support the development of computer science education in China.

At present, Shanghai Jiao Tong University has completed the course system and knowledge map arrangement, white paper writing, and platform construction in “101 plan”. 6 courses have been participating in classroom teaching effect evaluations, while 7 experts have been actively participating in course observation and guidance work for other schools. Meanwhile, driven by the curriculum construction team, Shanghai Jiao Tong University has already formulated a "101 plan" textbook publishing plan with multiple publication houses. "Data Structure", "Operating System", "Discrete Mathematics", and "Programming Language Design" courses are expected to complete in the first half of 2023, and officially published at the end of the year.

### 4.4 Explorations on Competency Development

Shanghai Jiao Tong University launched the "Participation in Research Program" (referred to as PRP) in 2001 for Competency Development. It has been included in the overall planning of the undergraduate training plan. This program aims to organize undergraduate students to participate in the research work of extracurricular scientific research projects and receive basic training in scientific research as soon as possible. The topics of the program are in line with the need of cultivating high-quality innovative talents with the characteristics of generosity, compoundness, openness, and innovation. Students are encouraged to carry out extracurricular science and technology, experiments, and innovative practice activities. The projects are declared by senior researchers and professors, which should organically combine theoretical teaching, practical teaching, and scientific research, carry out research-based learning, and cultivate students’ practical ability and innovative consciousness. [2]

During the implementation of the program, it is required to develop the following scientific research abilities, including active investigations, literature consulting, analysis and demonstrating, design plans formulation, calculation or experiments, summary and paper writing, etc. The students are suggested to work independently under the supervision of their instructors. All experimental centers and laboratories in the whole school are open to the students to support the carry-out of the project. [7]

Another competency development attempt is the Innovation and Entrepreneurship Program launched in 2010. Different from PRP, the principle followed by this innovation plan is interest-driven, independent experimentation, and focusing on the process. All projects are declared by students who have a strong interest in scientific research or creation and invention. They must design, complete, and manage the practice plans independently. Real recording of the entire process of project implementation, as well as the spiritual insights and various gains, are outputs of the projects. Achievements have won awards in various competitions such as the national intelligent car competition for college students or the ACM program design competition.

### 4.5 Other Featured Explorations

Shanghai Jiao Tong University has never stopped in the journey of creating “world-class undergraduate education without going abroad”. It promotes interdisciplinary cooperation, especially in computer science education.

To be specific, Shanghai Jiao Tong University has set up an artificial intelligence class, where the college’s seven first-level disciplines and Turing Research Center provide a high-quality teaching guarantee. It has attached great importance to artificial intelligence and computers, with the integration of mathematics, statistics, physics, biology, psychology, medicine, and other disciplines and professional education, exploring a new model of "artificial intelligence + X" compound professional training.

At present, four open Fab-Labs of robotics, drones, IT, and intelligent manufacturing, as well as multiple interdisciplinary innovation platforms such as the Zhiyuan Innovation Center are opening 7*24 hours a day. All kinds of inspiration
and creativity can be realized here immediately, creating an “aircraft carrier” for students’ technological innovation activities [5].

4.6 Undergraduate CS Education at Xiamen University

Xiamen University is also an active participant of the talent training plan or the 101 Plan. The undergraduate computer science program at

School of Informatics

Undergraduate CS education The School of Informatics of Xiamen University provides four undergraduate programs in the computing discipline: computer science and technology, cyberspace security, software engineering and artificial intelligence. Specifically, the computer science and technology program is equivalent to the computer science program in the United States. Freshmen undergraduates are enrolled into the computing discipline without a major assigned. In the first academic year, each student takes the same introductory computer science courses (e.g., introduction to computer science and introduction to programming) and math and physics courses (e.g., mechanics, calculus, and linear algebra), and applies to one of the programs above by the end of the freshman year. Their applications are reviewed and ranked based on their grades and extra curricular activities (e.g., the ACM-ICPC programming contest).

Starting from the sophomore year, students admitted to the computer science and technology program start to focus on computer science courses, including both introductory and advanced ones. Table XX provides the list of courses in the curriculum of the computer science and technology program in Xiamen University. Some of the courses are offered as both undergraduate and graduate levels. Senior students who are admitted as graduate students at XMU can take such courses and get graduate credits before they officially start their graduate studies. In the fourth year, each senior student also needs to finish a thesis study under the supervision of a faculty.

Strong Informatics Initiative. The School of Informatics at XMU follows the essence of the national talent training program to start its own strong informatics initiative in 2021. This initiative focuses on providing advanced courses ..

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Competency training. Take the algorithm

5 CONCLUSION

This paper reviews the efforts of Chinese CS educators in the past decade to reform the undergraduate computer science education in China, from the perspective of China’s nationwide reform initiatives, Chinese educators involvement in international reform projects and their practice experiences in developing students’ knowledge, skills and professional disposition in computer science. This paper does not raise any ethical issues.

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