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Improving Computer Science Curriculum and Teaching in the New Information Age

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Abstract This article presents the progress of Project 101, an initiative starting from December 2021, to improve computer science curriculum and teaching in top Chinese universities, in order to meet the demand of computer science eduction in the new information age. Project 101 aims at improving classroom teaching, while focusing on the development of core courses, core textbooks, core practice platforms, as well as core faculty training. We present an overview of the organization and plan of Project 101, as well as the current progress after two years' efforts from the working group of Project 101. Finally, we will also discuss tentative future plans aiming at improving computer science education in a large number of universities based on the current results.

Keywords Project 101, curriculum design, education reform, teaching improvement

1 Introduction

Computer science has been evolving rapidly since the beginning of the 21st century, as many new computing paradigms and applications have been developed with the emerging of mobile internet, cloud computing, Big Data, and artificial intelligence (AI). At the same time, computer science education has also undergone many innovations and reforming efforts (Clear et al., 2019). However, there is still room for improvement, especially on how to improve classroom teaching when we are facing an ever-increasing number of undergraduate students in the computer science discipline.

In December 2021, a pilot program was launched by the Ministry of Education of the People's Republic of China (MOE of China) for undergraduate education and teaching reform in the computer science discipline (referred to as Project 101). The vision of the program is to focus on improving the teaching and education in top computer science programs in China and making them world-class. The initial working group consisted of the top 33 universities that offered education experiences in computer science in China.

Project 101 has been led by Peking University (PKU), with the former President Ping Hao and current President Qihuang Gong directly leading the efforts. They have nominated Zhenjiang Hu, the Dean of the School of Computer Science at PKU, to oversee the project. Each top university designated an individual for their university's activity in the project.

Project 101 consists of two main components: to create the content for key computer science courses and to improve the teaching quality of faculty in the key courses.

The first component under the leadership of Yao Guo, the Deputy Dean of the School of Computer Science at PKU, requests each of the 33 universities to identify the key undergraduate courses in computer science. Twelve courses are identified. Each course is assigned to a university that supplied a leading faculty member to develop the content. The leading faculty member then formed a team of approximately a dozen top faculty in China in the subject matter of the course. The team identified 50 or more topics the course should cover and each topic is developed by a sub-team of the faculty.

The second component of improving the teaching quality of faculty, under the leadership of Xiaoming Li, involves a faculty member sitting in on a lecture and observing how the students respond to what the faculty member teaching the course says. When the lecture is finished, the faculty member who sits in on and the faculty member who gives the lecture would discuss how the lecture goes. This technique comes from a program to evaluate computer science programs at the top 50 universities in China.[1]

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1 The Award Program for Excellent Computer Science Major Faculty Members has been initiated by John E. Hopcroft and Wen Gao, which has generated extensive influence in promoting computer science education in China.

Here it is important to let the faculty teach the way they are comfortable and to select the material that they feel is important for their students. The intent is to have faculty sit in on lectures and tell that faculty member teaching the course how the students responded, then let the faculty member teaching the course figure out how they can improve their teaching quality. We need to let the faculty teach the way they are comfortable and not to force them to teach the way we used.

Project 101 has been in development for two years and it has accomplished its initial goals in the development of core courses, core textbooks, core practice platforms, and core faculty training. This article will give an overview of the organization, practice and progress of Project 101, as well as discussing the tentative future plans.

2 Overview of Project 101

2.1 | Organizational Structure

Under the guidance of the Department of Higher Education of the MOE of China, Project 101 has formed a working group including the 33 top universities, which is responsible for arranging the specific tasks of each university and supervising and coordinating the progress.

Project 101 has appointed an expert committee, which includes seven internationally renowned experts in the computer science field, including John E. Hopcroft, Manuel Blum, Silvio Micali, Andrew Chi-Chih Yao, Lyu Jian, Huaimin Wang, and Zhaohui Wu. All experts are either member of the Chinese Academy of Sciences or the US National Academy of Sciences/Engineering, and four of them are Turing Award winners. The expert committee effectively plays the role of consultation and guidance and is deeply involved in the construction of courses, textbooks, faculty, and practical platforms.

To support the work of the working group, the Project 101 secretariat was established at PKU to organize and coordinate general task arrangements. To work on specific tasks, a curriculum development group and a teaching promotion group have been formed, which are responsible for core curriculum development and teaching improvement (classroom observation), respectively. The curriculum development group focuses on the development of core major courses, systematically constructs the curriculum and teaching materials, and forms a complete computer science core curriculum through the construction of course knowledge points, online resources, and practice platforms. The teaching improvement group adopts the teaching reform practice of computer science majors aimed at teaching improvement, including class observation, lecture feedback, teaching method discussion, faculty training, etc., to improve the quality of classroom teaching and learning. The overall organization of Project 101 is shown in Figure 1.

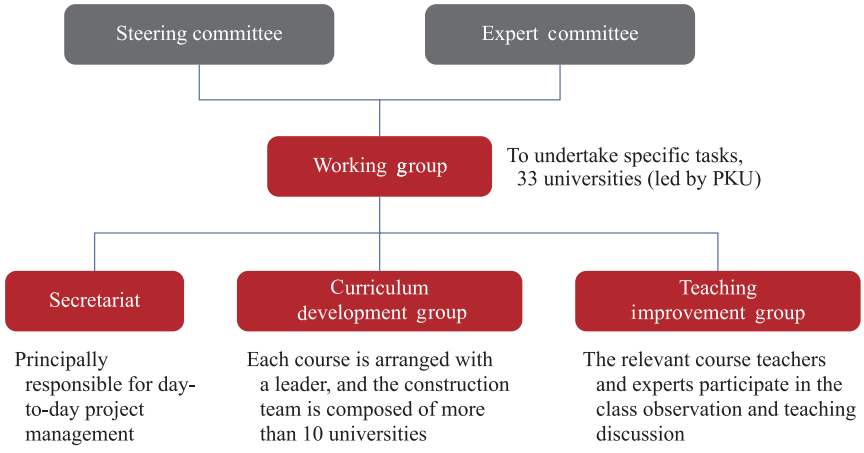

Figure 1 The Organizational Structure of Project 101

2.2 | Major Goals: The "Four Cores"

Project 101 takes the reform of computer science teaching and education as the starting point, deepens the reform of curriculum and teaching materials and relies on open collaboration to explore the new concept of talent, education, and science in the field of computer science, which will finally lead and drive the overall improvement of the quality of talent training in universities and colleges of China. Through the implementation of Project 101, it is necessary to take the lead in creating a set of first-class core courses in computer science, developing a set of first-class core textbooks, building a high-level core faculty team, and a set of core practice platforms, as well as explore a new model for the cultivation of high-quality talents in the field of computer science and contribute

to the construction of an independent training system for high-quality talents (as shown in Figure 2).

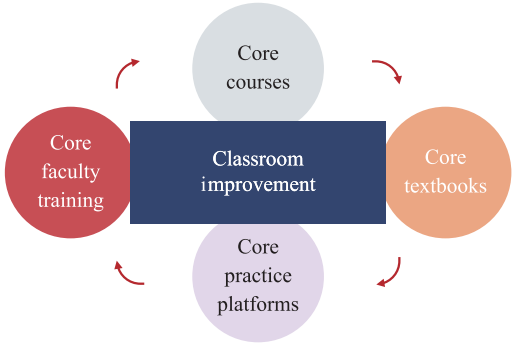

Figure 2 The "Four Cores" of Project 101

3 Current Progress of Project 101

With the meticulous guidance of the MOE of China and the strong support of the leadership of PKU, the working group has worked intensively during the past two years to achieve important results in core courses, core teaching materials, core faculty training, and core practice platforms.

3.1 | Core Courses

The construction of core curriculum knowledge graphs and supporting white papers (Hu & Guo, 2023) and supporting portfolios are now finished. The 12 core courses, shown in Figure 3, include Introduction to Computing, Data Structure, Algorithm Design and Analysis, Discrete Mathematics, Introduction to Computer Systems, Operating Systems, Computer Organization and Architecture, Compiler Principles, Computer Networks, Introduction to Database Systems, Software Engineering, and Introduction to AI.

The curriculum for a degree must enable students to acquire discipline skills in a progressive sequence of mastery (Gluga et al., 2013). Design of the course was complicated due to perceived differences in the needs of the different groups of students. Focusing on the key issues that need to be solved in undergraduate computer teaching and education, each core course construction team researched the subject organization, talent training principles, and talent needs of top foreign universities with computer science majors such as Massachusetts Institute of Technology, Stanford University, Carnegie Mellon University, and Princeton University. After many sessions of analyses, discussions and reviews, the course content was decomposed into more than 110 modules and more than 650 key knowledge points. Based on the research results, Project 101 core course system has been constructed, and published in the white paper (Hu & Guo, 2023), as a cornerstone to support the improvement of classroom teaching, the compilation of course materials, the deployment of training projects, and smoothly development of core faculty team. Table 1 shows an example of the course design of "Algorithm Design and Analysis" from the white paper, which includes 13 modules and 52 topics (knowledge points), with total suggested hours of 67.5 (each instructor is free to choose the required content and topics that fit into his/her course).

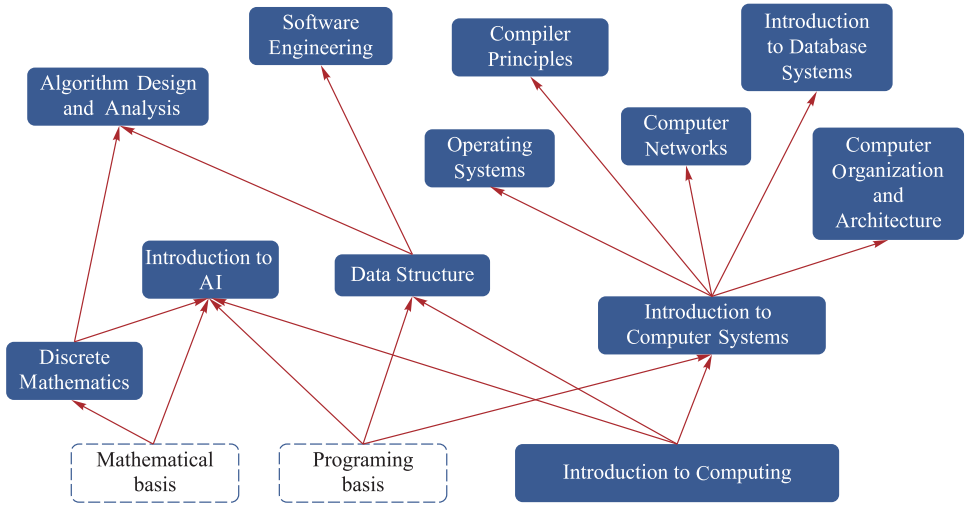

Figure 3 The List of 12 Core Courses in Project 101

Table 1 A Sample Course Design, with 52 Knowledge Points (Topics) from the Course "Algorithm Design and Analysis"

Module	List of topics	Suggested hours
1. Introduction to algorithm analysis	Computational complexity and asymptotic analysis (1), recurrence equation (1), generation function (1), master theorem (1), algorithm proof (0.5)	4.5
2. Divide-and-conquer strategy	Introduction to divide-and-conquer (2), optimization method (1), convolution and FFT (1)	4.0
3. Dynamic programming	Introduction to dynamic programming (1), implementation of dynamic programming (1), algorithms for classical problems (2), optimizations of dynamic programming (1)	5.0
4. Greedy algorithms	Introduction to greedy algorithms (2), mastoids and greedy methods (2), advance topics on greedy methods (2)	6.0
5. Backtracking/branch-and-bound	All valid solutions by backtracking (1), optimal solution by backtracking (2), branch-and-bound methods (2)	5.0
6. Amortized analysis	Amortized analysis (2)	2.0
7. Linear programming	Basis of linear programming (0.5), simplex method (1), duality (1.5), integer linear programming (0.5)	3.5
8. Network flow	The concept and nature of maximum flow (0.5), Ford Fulkerson algorithm (0.5), the correctness proof of the Fend Fulkerson algorithm (0.5), Edmonds-Karp algorithms (0.5), Dinic algorithm (1), Push-Relabel algorithms (2), maximum matching of bipartite graph (0.5), Hungarian algorithm (0.5), Hoperoft-Karp algorithm (0.5), minimum-cost flow (0.5)	7.0
9. Computational complexity of problem	Introduction to complexity of problem (0.5), decision tree (l.5), adversary argument (1.5), reduction (0.5)	4.0
10. NP completeness	P class and NP class (1), polynomial-time reduction and NP-completeness (1), proof of NP-completeness (2)	4.0
11. Approximation algorithms	Basics of approximation algorithms (2), approximation algorithms for parallel machine scheduling (2), approximation algorithms for the traveling salesman problem (TSP) (2), approximation schemes for knapsack problem (2)	8.0
12. Randomized algorithms	Introduction to probability theory (1.5), balls and boxes (1), Las Vegas algorithms (2), Monte Carlo algorithms (2)	6.5
13. Online algorithms	Introduction to online algorithms (2), online algorithm for cache replacement (2), online algorithms for set cover (2), variants of models for online computation (2)	8.0
Total	52	67.5

Over several offerings of the course, it became apparent that the real issues in the course development were not in the selection of topics, rather they came from decisions regarding things such as teaching and learning modes, depth of coverage, ordering of supporting topics and review of prerequisite knowledge (Doherty, 2011). As one of the most important elements for curriculum development in Project 101, the portfolios (teaching materials) aim at improving classroom quality, while the implementation of the portfolios will serve as the foothold to explore the various perspective of each knowledge point, including teaching goals, and suggested hours, teaching content and methods, learning difficulties, leading questions, discussion or other classroom activity design. Through classroom practice of Project 101, the curriculum development group completed a total of 859 pieces of teaching materials to form the portfolios, which can be accessed from on the Project 101 official website (https://101.pku.edu.cn). At the same time, to adapt to cutting-edge research developments in computer science, Project 101 also wrote more than 30 pieces of teaching materials on special knowledge point sets including "Quantum Computing" and "Large Language Models" (LLMs).

3.2 | Core Textbooks

Based on the review and analysis of popular computer science textbooks used worldwide, with the core curriculum development teams of Project 101 as the backbone, the development of core textbooks has brought together experts and scholars with the richest teaching experience and the highest academic level in the computer science discipline in China. Project 101 plans to publish 31 core textbooks, with no more than three textbooks for each course. Concurrently, we will explore the innovation of integrated digital publishing, constructing the textbook ecology with core digital contents and multimedia resources.

To ensure the quality of the textbooks, 33 senior experts from 23 universities have participated in the evaluation of the textbook design and plans. The expert groups listened to the introduction of the arrangements

and contents of the textbooks by the course leaders and the main authors, reviewed the planning, content, and sample chapters, and put forward valuable suggestions on the writing of the textbooks, according to the requirements for the publication of the Project 101 textbooks. The expert groups acknowledged that most of the textbooks have wide coverage, novel ideas, and rich supporting resources, which are important explorations for the establishment of high-quality new curriculum textbooks for computer science majors. They also provided many suggestions for improvement from the aspects of the textbook titles, structure layout, content applicability and uniformity, lab/project settings, learning feedback, practical cases, teaching resources, and so on.

During the fall semester of 2023, we used the core textbooks to carry out teaching trials at a wide range of universities, received feedback on the trial use and suggestions, and further supported the revision and improvement of the core textbooks and high-quality publication. The working group selected 58 courses from 40 colleges and universities to carry out the pilot trial covering textbooks in 12 core courses. The main authors of the textbook provide teaching guidance for the trial of specific textbooks through regular teaching seminars. At the beginning of November, the mid-term debriefing and collective lesson preparation activities for the pilot application of textbooks were carried out at Wuhan University. The pilot colleges and universities applied and provided suggestions about the contents of the textbooks and the supporting experiments from the aspects of ideology, advancement, applicability, and practicality, and revised the syllabus according to the training objectives and students' conditions.

3.3 | Core Faculty Training

To reasonably reflect the modern capabilities of computing technology and its uses in society, the contents of courses in computer science must continually evolve and the shift in content is sufficient to demand corresponding changes in course organization and student activities (Chamillards & Merkle, 2002). With the ultimate goal of improving the effectiveness of classroom teaching, Project 101 focuses on the teaching of teachers and students' learning through the recording, analysis and research of classroom activities, striving to form a consensus that adapts to the new principles of Chinese university classrooms. Classroom observation ensures effective communication of teaching improvement through three main links. The first is the preparation before the lecture, the faculty member who gives the lecture provides the basic information about the course (including course syllabus, teaching objectives, content outline, etc.), and communicates with the faculty members who will sit in on this lecture in advance. The second is the observation of teaching, in which the faculty members who sit in on the lecture take on the role of the teaching according to their own experience through the whole process, and complete the lecture feedback form. Finally, there is a post-class discussion, where the faculty members involve in the lecture have an in-depth discussion on the course contents, teaching methods, and assessment approaches. In addition to the above classroom observation process, faculty experts also conduct multiple rounds of observations for the same lecture and provide more specific suggestions.

As an important teaching improvement activity, 234 faculty experts (494 lecture observations) from 33 universities have participated in 288 lecture activities (for 168 courses) and completed 491 lecture records. Through pre-class preparation, on-site observation, and post-class communication, the instructors are able to discuss the best practices of teaching and form some consensus and suggestions with guiding significance. Through continuous classroom observations and feedback, the teaching process is continuously optimized, and the teaching ability of teachers and the learning of students are improved. Our detailed mechanism for observing classrooms has been implemented, which will ultimately lead to the sustainable development of computer science education.

To realize the sharing of high-quality teaching and research resources, and to form a sustainable mechanism of teacher development that will promote teaching reform and innovation, the Project 101 has established 13 virtual teaching labs for core courses, and founded a virtual discipline collaboration group, which attracts 489 faculty members from different universities to exchange and discuss together. Each virtual teaching lab provides the mechanisms and fully exploits the construction advantages of collaboration between universities and related institutions, which, during the past year, carried out 175 teaching and research activities (664 faculty members participated), and submitted 1,895 teaching resource documents to the virtual labs.

Project 101 has organized a series of core faculty training sessions based on curriculum development results to play a leading role in training a group of excellent core course instructors and improving the effectiveness and quality of classroom teaching. The training event is based on the collaboration of the working group, the virtual teaching and research labs, and academic groups such as the China Computer Federation and the Guizhou Computer Federation, with the assistance of publishers, educational technology companies, and the support by many universities. The main training contents include experts from the curriculum development group to provide on-site guidance and demonstrations on core curriculum content, specially invited experts in relevant fields to provide professional guidance on improving teachers' comprehensive abilities, sharing

experiences with outstanding teachers from partner institutions, and training on scenario-based and case-based practical teaching. During the past year, over 560 teachers from more than 190 colleges and universities have participated in the on-site training sessions, jointly explored teaching improvement through discussions and exchanges, built targeted teaching content, strengthened teaching exchanges between teachers from different universities, and promoted teachers across schools and regions to develop a high-quality curriculum system and resources.

3.4 | Core Practice Platforms

For many traditional courses, a longstanding problem is the lack of sufficient practice exercises with feedback to the student (Fouh et al., 2014). The construction of core practice platforms is another main task of computer science education, and it is also an important measure to carry out multi-party collaborative education and strengthen the integration of production and education. According to the overall plan, the Project 101 has established supporting practice platforms and practice teaching materials, organized innovation ability competitions, promoted relative companies to participate in curriculum practice, and held a special forum on the construction of the practice platform to jointly discuss the cutting-edge topics of practical teaching of core courses for computer majors.

The course development teams have developed practice and lab content that matches core courses, and have built 46 typical course project sets in conjunction with practical teaching support organizations in the computer science areas such as EduCoder and CourseGrading, with support from top enterprises such as Alibaba, Huawei, including more than 400 lab projects, 252,542 people participated in practical interactions, and the number of evaluation submissions reached 2,446,890 times. Meanwhile, 11 practice platforms have been established, including 54 practice projects, and more than 46,137 people participated in practical training and teaching.

The construction of the Project 101 practice platforms is based on the knowledge graphs of the core curriculum, guided by the structure of students' practical ability training, and oriented to the actual needs of society. At the moment, major functional modules of the Project 101 practice platform have been completed and have been deployed online. The platform provides contents including course lists and development results, textbook recommendations, teacher training information, and practice project resources. To further improve core teaching cases and resources, and comprehensively integrate and optimize theoretical knowledge, core technology, and cultivation skills involved in teaching, each curriculum development team has compiled supporting practical teaching materials based on the existing practice platform, and more than 40 teachers plan to publish 23 course practice textbooks to promote relevant practical teaching experience.

4 Future Plans

When the Project 101 is created, it is restricted to one discipline (computer science) and the top computer science departments. A small project is created to ensure that it works well before focusing on creating material for other institutions. Now it needs to be expanded to create material for more than 1,000 universities with computer science majors in China.

What is being taught at the other institutions may be much different from what is taught at the top 33 universities. The top faculty in China created materials that are excellent but may be too sophisticated and theoretical for many of the other universities. The vast majority of students go to the other institutions, who get jobs in application industry and need more application material. This will require the faculty from the other institutions to create material that is more appropriate for their students.

The second phase of Project 101 needs to involve these institutions to increase new directions. This phase of the effort to improve higher education in China is a complicated task and will require learning what is needed for universities at different levels and creating material that will meet the needs of all universities.

Tentative future plans may include a top-down approach to promote achievements with the Project 101 and modify the materials to accommodate over 1,000 universities with computer science major, which will involve more faculty members beyond the 33 initial universities and additional universities in classroom evaluation/improvement. At the same time, the authors will explore methods to evaluate and improve classroom teaching, and hopefully develop AI-enabled methods to evaluate teaching so that we can save the time of faculty experts for sit-in evaluation.

5 Concluding Remarks

After two years of efforts by the 33 universities since December 2021, the Project 101 has achieved most of its initial goals in developing core courses, core textbooks, core practice platforms and core faculty training. Based on the successful experience of Project 101 on computer science, the strategy has been expanded to other disciplines such as mathematics, physics, chemistry, biology. Hopefully, it could serve as a major step in making China the leading country in science and engineering education.

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Conflict of Interest The authors declare that they have no conflict of interest.

References

Chamillard, A. T., & Merkle, L. D. (2002). Evolution of an introductory computer science course: The long haul. *Journal of Computing Sciences in Colleges*, (1), 144–153.

Clear, A., Parrish, A. S., Impagliazzo, J., & Zhang, M. (2019). Computing curricula 2020: Introduction and community engagement. In: Proceedings of the 50th ACM technical symposium on computer science education, ACM, New York, NY, USA, 653–654.

Doherty, M. (2011). Learning objective based design of a computer simulation course. *Journal of Computing Sciences in Colleges*, (4), 181–188.

Fouh, E., Breakiron, D. A., Hamouda, S., Farghally, M. F., & Shaffer, C. A. (2014). Exploring students learning behavior with an interactive etextbook in computer science courses. *Computers in Human Behavior*, 478–485.

Gluga, R., Kay, J., Lister, R., Simon, & Kleitman, S. (2013). Mastering cognitive development theory in computer science education. *Computer Science Education*, (1), 24–57.

Hu Z., & Guo, Y. (2023). *Strategic research report of talent cultivation and core course curriculum for computer science majors in higher education*. Beijing: Higher Education Press.