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PERSPECTIVE

Integration of science and education: Reform and practice of innovative talent cultivation model in the field of communication engineering

Guang Wu, Qingfeng Zhang*

Department of Electronic and Electrical Engineering, Southern University of Science and Technology, Shenzhen 518055, Guangdong Province, China

INTRODUCTION

In recent years, with the growing surge in the demand for digitalization across various industries. Emerging next-generation communication technologies such as 5G combined with cloud networking, artificial intelligence, and the Internet of Things (IoT) are swiftly advancing as core sectors within the digital economy, aiming to meet the evolving societal needs of the contemporary landscape. Against this backdrop, the integration between the communication field and industry has become notably tighter, posing fresh challenges for talent development and curriculum enhancement in communication engineering programs at higher education institutions.[1]

Nowadays, high-level research-oriented universities have become the main force leading technological innovation. However, how to leverage scientific research advantages and promote undergraduate teaching reform and development is a significant challenge. From an educational perspective, undergraduate engineering education focuses on enhancing students' ability to solve complex engineering problems.[2] However, for a long time, undergraduate teaching in communication engineering has been predominantly theoretical, lacking corresponding experimental/practical courses. Moreover, the teaching content has often failed to keep pace with industry trends, while the communication industry requires talents with innovative practical abilities, leading to the so-called "industry-education gap". To address this issue, some universities have adopted software simulation, such as MATLAB/Simulink or LabVIEW, in their experimental teaching programs to enhance students' experimental abilities.[3] Other approaches integrate hardware experimental platforms such as Universal Software Radio Peripheral (USRP) and Realtek Software Defined Radio (RTL-SDR) into experimental teaching.[4,5] However, these approaches either lack hardware experimental verification or lack cutting-edge teaching case designs, making it difficult for students to improve their experimental abilities. On the other hand, in extracurricular practical activities, traditional internship programs are almost outdated and have remained unchanged for many years, lacking innovative and autonomous practical projects to enhance students' innovative practical abilities.

In order to leverage scientific research advantages, promote undergraduate teaching reform, and finally achieve integration of science and education, in the past two years, we have implemented the new talent cultivation model characterized by equal emphasis on theory and experimentation, integration of software and hardware teaching, research-driven teaching, software-hardware design, and artificial intelligence (AI)-driven instruction. Since the implementation of this program, significant outcomes have been achieved. In undergraduate competitions such as the University Electronic Design Competition, undergraduate students have won over 30 awards. Moreover, undergraduate

***Corresponding Author:**
Qingfeng Zhang, Department of Electronic and Electrical Engineering, No. 1088 Xueyuan Avenue, Nanshan District, Shenzhen 518055, Guangdong Province, China.
Email: zhangqf@sustech.edu.cn; https://orcid.org/0000-0002-0038-0694
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students have participated in publishing over 15 papers in renowned journals or conferences, including Institute of Electrical and Electronics Engineers (IEEE) Transactions on Wireless Communications and IEEE Vehicular Technology Conference.[6–9] Over 60% of students have been able to achieve competition awards or paper publications. In terms of curriculum development, teachers are actively encouraged to design research projects into teaching cases, with over 8 winning cases in university experimental case design competitions. In the cultivation of students' software-hardware design abilities, over 90 students annually participate in Advanced Electronic Science Experiment II/III, joining over 40 faculty research groups to enhance their software-hardware design capabilities. In AI-driven teaching, through the establishment of the Ministry of Education's collaborative education project with industry, advanced communication system experiments based on MATLAB's deep learning toolbox have been introduced to enhance the curriculum's innovation in the context of the new engineering disciplines. Therefore, our talent cultivation model has won the second prize of Guangdong Province Education and Teaching Achievement Award and the second prize of Southern University of Science and Technology Teaching Achievement Award. In the following sections, we will introduce the significant improvements of the talent cultivation model.

IMPROVEMENT I: EQUAL EMPHASIS ON THEORY AND EXPERIMENTATION

Fundamentally, we have optimized the original talent training program, focusing on increasing the proportion of experimental/practical components. For example, in the undergraduate program for communication engineering majors, a total of 19 specialized compulsory courses are offered, including 10 foundational courses, 7 core courses, and 2 intensive practical courses, as shown in the Table 1. It's worth noting that 84% of the specialized courses incorporate experimental/practical components, with experimental/practical credits accounting for 47% of the total credits for specialized compulsory courses.

In the experimental/practical teaching component, both software and hardware teaching are given equal importance. Students are required to learn programming and simulation software such as MATLAB, LabVIEW, Python, Android Studio, and High-Frequency Structural Simulator (HFSS), while also conducting experiments with hardware platforms such as USRP, Vector Network Analyzer (VNA), Raspberry Pi, signal generators, digital oscilloscopes, spectrum analyzers, and others. Through the optimization of the training program and reforms in experimental/practical teaching, students' hands-on abilities have significantly improved. In hardware and software design competitions such as the University Electronic Design Competition, students have won over 30 awards.

IMPROVEMENT II: RESEARCH-DRIVEN TEACHING

In order to leverage scientific research advantages to solve the issue of outdated teaching content, on the one hand, we have encouraged professors to design teaching cases according to their own research projects. On the other hand, we have set up a compulsory course, that is the Advanced Electronic Science Experiment II/III. Through the courses, students choose to participate in professors' research projects based on their own interests.

In fact, most of the traditional teaching content in communication majors has struggled to keep pace with industry trends due to the rapid development of the communication industry. To address this issue, professors have tailored their research findings into suitable case studies for undergraduate teaching to enhance the cutting-edge innovation of the curriculum. For instance, in the course such as Signal and Systems, research projects like "Motion Detection Based on Communication Signals" have been designed into teaching cases. This case study won the Second Prize in the South-Central Division of the 10th National University Electrical and Electronic Fundamentals Experimental Case Competition. Similarly, teaching cases designed for courses like Communication Principles and Wireless Communication, such as the "USRP Image/Text Transmission Experiment", won the Second Prize in the National Finals of the Second National Electronic Information Professional Course Experimental Teaching Case Design Competition. Case design must meet engineering certification requirements and undergo practical teaching verification. The design process includes background introduction, principle explanation, hardware experimentation, group discussions, teamwork, flipped classrooms, group presentations, and project reports. Through these processes, student experimental achievements are monitored and observed.

In extracurricular experimental teaching, such as in the Advanced Electronic Science Experiment II/III course, students choose a corresponding supervising professor based on their research interests and complete a software-hardware design project. Through participation in the supervising professor's research projects, students' scientific literacy, self-learning abilities, and innovative thinking are significantly enhanced.

Table 1: New program of communication engineering

Course category	Course code	Course name	Credits	Practices-based learning credits
Major foundational courses	EE104	Fundamentals of Electric Circuits	2	0
	EE201-17	Analog Circuits	3	0
	EE201-17 L	Analog Circuits Laboratory	1	1
	EE205	Signals and Systems	3	1
	EE207	Engineering Mathematics	4	0
	EE202-17	Digital Circuits	3	0
	EE202-17 L	Digital Circuits Laboratory	1	1
	EE208	Engineering Electromagnetics	3	1
	MA212	Probability and Statistics	3	0
	EE351	Microprocessors and Microsystems	3	1
	Total		26	5
Major core courses	EE206	Communication Principles	3	1
	EE317	Advanced Electronic Science Experiment I	1	1
	EE313	Wireless Communications	3	1
	EE316	Microwave Engineering	3	1
	EE318	Advanced Electronic Science Experiment II	1	1
	EE307	Antennas and Radio Propagation	3	1
	EE405	Advanced Electronic Science Experiment III	1	1
	Total		15	7
Practice-based courses	EE470	Internship	2	2
	EE492	Undergraduate Thesis/Projects	12	12
	Total		14	14
Total			55	26

IMPROVEMENT III: SOFTWARE-HARDWARE DESIGN AND DIVERSIFIED TALENT CULTIVATION

In response to the issues of insufficient software-hardware design skills among students and the lack of diversified talent cultivation, the innovative talent cultivation model requires every undergraduate student to independently design and complete both a functional hardware device and a working mobile application. This aims to equip students with comprehensive abilities ranging from hardware design to software development. This initiative has been covered by the China Daily newspaper.

The Advanced Electronic Science Experiment II/III serve as a platform for cultivating students' software-hardware design abilities and promoting diversified talent development. In this course, instructors integrate specific research projects or enterprise development projects to arrange software and hardware design tasks tailored to students of different academic levels. These tasks progress from basic to advanced research or development assignments. Students have the autonomy to choose software and hardware projects according to their interests. Approximately 90 students participate in the Advanced Electronic Science Experiment II/III each year, joining over 40 faculty research groups to complete more than 100 software-hardware design projects. Throughout the process, students are required to submit project proposals, undergo midterm assessments, and participate in final assessments. During the final assessment phase, students must engage in offline presentations and undergo evaluation and scoring by at least three expert reviewers.

From the completion perspective, 100% of students are able to, under the guidance of their mentors, complete the research and final assessment of their chosen projects. Outstanding software-hardware design projects will be selected through the final assessment, and outstanding project certificates will be awarded. By conducting discussions with the recipients of outstanding projects and collecting feedback, the course continuously improves.

Furthermore, as students' software-hardware design abilities improve, they are also capable of independently securing project funding. Since the implementation of the talent cultivation model, students have obtained funding for over 20 projects through the Undergraduate Innovation and Entrepreneurship Training Program and funding for over 10 projects through the "Climbing Program", which refers to the specialized program aimed at fostering and enhancing the technological innovation capabilities of university students in Guangdong Province.

IMPROVEMENT IV: TEACHING REFORM DRIVEN BY ARTIFICIAL INTELLIGENCE

Finally, we actively introduce AI technology into curriculum teaching. In recent years, as artificial intelligence has matured, deep learning has rapidly been applied to various fields of science and engineering, such as computer vision, image processing, and autonomous driving. Concurrently, companies like MathWorks, National Instruments, and Beijing IECUBE Technology have introduced corresponding AI teaching solutions to drive educational reform. For example, MathWorks' Deep Learning Toolbox provides a framework for designing and implementing deep neural networks through algorithms, pre-trained models, and applications. In the field of wireless communication, by integrating the Deep Learning Toolbox with toolboxes like Communications Toolbox, LTE Toolbox, 5G Toolbox, and WLAN Toolbox, deep learning is applied to simulate wireless communication systems.

In terms of AI+ curriculum development, efforts have been made to enhance the cutting-edge innovation of educational content through the establishment of collaborative projects between the Ministry of Education and industry partners. For instance, the "Target Signal Modulation Recognition and Localization Based on Deep Learning" project aims to strengthen the forefront of teaching content. For example, in the Experimental Course of "Advanced Communication System Design", an experiment project based on the Deep Learning Toolbox, namely "Modulation Recognition Based on Deep Learning", has been added to the existing experiments. This project utilizes Convolutional Neural Networks (CNN) for modulation classification, employs generated waveforms as training data, trains CNN for modulation classification, and finally tests CNN with software-defined radio hardware and wireless signal. These AI-based communication system projects serve as crucial references for the continuous improvement of communication major courses, playing a pivotal role in the reform of course forefront and the cultivation of students' ability to solve complex engineering problems.

CONCLUSION

With the close integration of the communication profession and industry, the shortcomings in the traditional talent cultivation process, such as the emphasis on theory over practical skills, simulation over hardware, outdated teaching content, single-minded talent development, and insufficient software-hardware design abilities, have become increasingly apparent. In order to leverage scientific research advantages, promote undergraduate teaching reform, and achieve integration of science and education, we have implemented the new talent cultivation model characterized by an equal emphasis on theory and experimentation, software and hardware teaching, research-driven education, and AI-driven innovation. Since the implementation of the new program, significant progress has been achieved in disciplines competitions, undergraduate publications, curriculum content development, software-hardware design abilities and fostering innovative talents.

DECLARATIONS

Author contributions

Wu G: Conceptualization, Writing—Original draft preparation, Writing—Reviewing and Editing. Zhang QF: Conceptualization, Supervision. All authors have read and approved the final version of the manuscript.

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Conflict of interest

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Not additional data.

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