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The Impact of FDI Technology Spillovers on Technological Progress in China's Computer, Communication, and Other Electronic Equipment Manufacturing Industry: A Study Based on a Panel Smooth Transition Regression Model

Liyang Qi, Weiran Wang*
Business School, Xinjiang Normal University, Urumqi 830017, Xinjiang, China

***Corresponding author:** Weiran Wang, wangweiran@163.com

Abstract:

With the development of economic globalization, foreign direct investment (FDI) has become a key area of focus for governments and academic research as an important means of strengthening international economic ties and promoting domestic economic development. The impact of technology spillover effects from direct investment on technological progress in host countries has also attracted widespread attention from scholars both domestically and internationally. Based on panel data from the computer, communication, and other electronic equipment manufacturing industry in 25 provinces in China from 2001 to 2021, this study employs a panel smooth transition regression model using MATLAB to investigate the impact of FDI horizontal spillover effects on technological progress in the industry, with R&D funding and R&D personnel input as transition variables. The findings of the study are as follows: (1) There is a nonlinear relationship between FDI horizontal technology spillovers and technological progress in the industry, and there are significant regional differences in the linear relationship. (2) From a national perspective, FDI horizontal technology spillovers promote technological progress in the industry, but when R&D personnel input exceeds a threshold value, FDI horizontal technology spillovers hinder technological progress in the industry. (3) At the regional level, FDI horizontal technology spillovers in the eastern region promote technological progress in the industry. However, when both R&D funding and R&D personnel input exceed their respective threshold values, FDI horizontal technology spillovers hinder technological progress in the industry. In the central and western regions, there is a linear relationship between FDI horizontal technology spillovers and technological progress in the industry. (4) The increase in FDI horizontal technology spillovers in the eastern region leads to a shift in the pathway of technological progress in the industry, from relying on technology spillovers to independent research and development.

Keywords:

FDI horizontal spillovers
Panel smooth transition regression model
Computer, communication, and other electronic equipment manufacturing industry
Technological progress
Absorptive capacity

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1. Introduction

After the reform and opening up, China has steadily increased its attraction of foreign direct investment (FDI), with actual utilization of FDI rising from US 113.3 billion in 2012 to US 173.5 billion in 2021, representing an average annual growth rate of 4.8%. Since 2020, China has ranked second in the world in terms of FDI attraction. The inflow of FDI can bring technology spillover effects to the host country, which are classified into two types: horizontal and vertical spillovers, based on the direction of the spillover. Regarding vertical spillover effects, Chinese scholars have generally reached a consensus that they are positive. However, there is significant disagreement on whether horizontal spillover effects are positive, negative, or insignificant.

China's computer, communication, and other electronic equipment manufacturing industry has made outstanding contributions to attracting FDI. From the perspective of actual FDI utilization, the cumulative amount of foreign capital utilized from 2001 to 2021 was 10,816.531 billion yuan, accounting for 20.67% of the total foreign capital utilized in the manufacturing industry. This industry ranks first in attracting FDI among the 21 sub-industries under the manufacturing sector. Simultaneously, the industry occupies a crucial position in China's high-tech industrial sector. Products in this industry undergo rapid upgrading, and technological progress and innovation are key concerns for all enterprises within the sector.

Technological progress in a country can be achieved primarily through two pathways: independent research and development (R&D) and the absorption of FDI technology spillovers. Since China's reform and opening up in the 1970s, it has continuously engaged in relevant practices, with the strategy of "exchanging the market for technology" being continuously tested in practice. Since then, China has introduced a large amount of foreign capital, alleviating capital shortages and relying on the resulting technology spillovers to promote domestic technological progress. However, the effectiveness of this approach has not met expectations. The technology dependence of China's computer, communication, and other electronic equipment manufacturing industry on foreign sources was above 40% before 2004, reaching 80%–90% in some years, indicating a high degree of external dependence on technological progress in the industry. It was only in 2008 that the industry's technology dependence on foreign sources gradually decreased to below 30%. The Ministry of Commerce pointed out in the "2005 Report on Multinational Companies in China" that "the result of a large amount of foreign direct investment is a lack of core technology." In 2006, China proposed strategies for rejuvenating the country through science and technology and promoting independent innovation. Yu believed that China's technological progress has since shifted from relying on foreign technology spillovers to focusing on independent innovation [1]. Therefore, it is of great practical significance to investigate whether FDI horizontal spillovers drive technological progress in this industry, how the industry can utilize FDI horizontal spillovers to promote technological advancement, and whether FDI horizontal technology spillovers can lead to a transformation in the pathways of technological progress within the industry.

2. Literature review

According to the definition provided by Blomström and Kokko [2], two of the most renowned scholars in the field of FDI spillover research, "FDI spillovers refer to the economic external effects that occur when multinational companies implement FDI in host countries, leading to local technological or productivity advancements, of which the multinational companies cannot capture all the benefits." FDI spillovers are classified into horizontal and vertical spillovers. Since the existence of FDI spillover effects was verified, a significant amount of literature on FDI spillover effects has been published. The number of studies on vertical spillovers is noticeably more than those on horizontal spillovers. Currently, scholars unanimously agree that the direction of vertical spillovers is positive, but there is still no consensus on the direction of horizontal technology spillovers. Fan and Wu [3] empirically tested the horizontal and vertical technology spillovers of FDI using panel data from 35 industrial sectors in China and concluded that FDI horizontal spillovers are negative. Bi and Yang [4] conducted an empirical analysis using relevant data from 23 industrial sectors over seven years and found that FDI horizontal spillover effects positively impact the reduction of carbon emission intensity. Zhao [5] studied the relationship between FDI technology spillovers and enterprise entry and exit in the manufacturing industry using three years of data from China's manufacturing sector. The results showed that FDI horizontal spillovers are significantly negative, reducing the entry rate of domestic enterprises. Yue [6] used a sample of 900,000 enterprises from 15 sub-sectors of China's manufacturing industry and found that upstream suppliers have a positive horizontal spillover effect on local enterprises. Chen and Lu [7] measured the horizontal technology spillover effects in 23 industrial sectors in China using technological similarity. They believed that significant spillover effects from foreign advanced technology can only occur when the technologies used within or between industries are similar and closely connected at the technological level. When technological similarity is not considered, the horizontal technology spillover effect is significantly negative.

After integrating the 39th industry, "Computer, Communication, and Other Electronic Equipment Manufacturing," under Category C of the "Classification of National Economic Industries" released by the National Bureau of Statistics of China in 2017, with the "Electronic and Communication Equipment Manufacturing" classification in China's high-tech industry classification, this paper found that eight out of the nine sub-categories within China's computer, communication, and other electronic equipment manufacturing industry fall under the electronic and communication equipment manufacturing classification. These are: communication equipment manufacturing, radio and television equipment manufacturing, radar and supporting equipment manufacturing, non-professional audio-visual equipment manufacturing, smart consumer device manufacturing, electronic component manufacturing, electronic parts and specialized electronic materials manufacturing, and other electronic equipment manufacturing. The ninth sub-category, computer manufacturing, overlaps highly with the sub-categories under the computer and office equipment manufacturing industry in China's high-tech industry classification. Therefore, the data for the threshold variables in this paper are selected from the electronic and communication equipment manufacturing and computer and office equipment manufacturing industries in China's high-tech industry database. Wang *et al.* [8] analyzed the R&D performance of the communication equipment, computer, and other electronic equipment manufacturing industry and found that since 2004, China's scientific and technological investment in this industry has been increasing continuously. As of 2004, a total of 210,800 scientific and technological personnel were invested, accounting for 11.47% of the total number of scientific and technological personnel in all industrial enterprises. The high investment and high output of scientific and technological activities and R&D activities in the communication equipment, computer, and other electronic equipment manufacturing industry have attracted more investment, and various regions have increased their scientific and technological investment in this industry. Zhu [9] analyzed the industrial efficiency of Shaanxi Province, taking the communication equipment manufacturing industry in the province as an example. The scientific and technological innovation platform is an important foundation for the scientific and technological innovation system of Shaanxi's communication equipment, computer, and other electronic equipment manufacturing industries, and it is an important carrier for promoting enterprises to become innovation subjects. Detailed suggestions were also provided for improving the independent innovation capability of the industry. Liu *et al.* [10] summarized the characteristics of the industry as being highly influenced by the macro environment, having strong technology, high investment, high risks, and rapid technological upgrades and product replacements when evaluating the value of mergers and acquisitions of micro-companies in the industry. This shows that the computer, communication, and other electronic equipment manufacturing industry has high requirements for technological levels. Analyzing whether FDI horizontal spillovers in this industry promote technological progress has practical significance.

The potential marginal contributions of this paper are as follows: (1) Industry focus: Examining the impact of FDI horizontal spillovers on technological progress in the computer, communication, and other electronic equipment manufacturing industry. Existing literature often selects broad categories such as manufacturing, services, and agriculture when studying FDI technology spillovers, with less focus on specific sub-sectors within these broader classifications. (2) Model innovation:

Utilizing MATLAB to conduct a Panel Smooth Transition Regression (PSTR) model to investigate the influence of FDI horizontal technology spillovers on technological advancement. Current research frequently employs Hansen's [11] threshold regression model (PTR) for nonlinear testing in related areas. However, this model uses a discrete indicator function, resulting in abrupt transitions at thresholds. Gonzalez *et al.* [12] introduced an improved PSTR model that incorporates a transformation function involving threshold variables, enabling smoother transitions at these points. (3) Extended time span: The sample period selected in this paper spans from 2001 to 2021, totaling 21 years of panel data, which enhances the persuasiveness of the results obtained.

3. Theoretical analysis and mechanism of action

3.1. Theoretical foundations of FDI spillover effects

3.1.1. Technology diffusion theory

Multinational corporations introduce advanced production technologies and management experiences into their investment target countries. When local businesses and labor forces collaborate or compete with these multinationals, they enhance their productivity and efficiency through technology transfer, skills training, and the absorption of management practices. This technology diffusion can generate positive spillover effects in the target investment countries and potentially similar impacts in other operational locations of the multinationals. This paper empirically analyzes whether such technology spillovers exist in the computer industry.

3.1.2. Human capital theory

When multinational companies invest in a country, they often provide high-quality employment opportunities, training and development programs, and experience related to international business. These investments may attract and retain local talent or draw foreign talent to the investing country. The increase in such talent can facilitate the flow of technology and knowledge, leading to spillover effects. As FDI flows into China's computer industry, relevant talent may gradually influx, potentially generating technology spillover effects. This paper intends to examine whether this phenomenon exists.

3.2. Mechanisms of FDI horizontal spillover effects

FDI horizontal technology spillovers occur within the same industry in the host country, also known as intra-industry technology spillovers. They primarily influence technological progress in the host country through competition effects, demonstration effects, and human resource mobility effects.

3.2.1. Competition effects

With the inflow of foreign capital, multinational corporations compete with domestic enterprises. To enhance their competitiveness in the market, host country enterprises shift their focus to improving their independent innovation capabilities, thereby promoting technological advancement in the host country. The competition effect is particularly prominent in the computer industry, where product updates are rapid, and independent innovation ability is a core competitiveness of enterprises.

3.2.2. Demonstration effects

The inflow of foreign capital provides a reference for innovation in host country enterprises. By imitating foreign-invested enterprises, host country businesses can stimulate their own innovation capabilities. As foreign capital flows in, some more advanced technologies may also enter the industry. However, computer companies typically have strong protections for their core technologies, which are not easily disclosed. Therefore, the effectiveness of this effect remains to be tested.

3.2.3. Human resource mobility effects

To ensure their smooth operation, foreign-invested enterprises train local employees. When these trained employees enter the job market, some may join host country enterprises and apply their acquired knowledge and skills, thereby contributing to technological progress in the host country. The computer industry experiences high employee turnover, and the human resource mobility effect resulting from foreign capital inflow influences technological advancement in the computer industry through talent influx.

4. Variables and data

4.1. Dependent variable

Total Factor Productivity (TFP): Referring to the method used by Wang and Lai [13] to calculate TFP in Shandong Province, this paper adopts the Solow residual method to calculate the TFP of various provinces in China from 2001 to 2021 in the computer, communication, and other electronic equipment manufacturing industries. TFP is used as an indicator to measure technological progress in this industry.

4.2. Core explanatory variable

Due to the lack of FDI values for various sub-sectors of the manufacturing industry, this paper refers to the method proposed by the Peking University China Economic Center Research Group [14]. It calculates the sum of foreign capital and Hong Kong, Macao, and Taiwan capital in the computer, communication, and other electronic equipment manufacturing industries in various provinces. The producer price index with 2001 as the base period (2001=100) is used to deflate it, and this data is used to measure the level of FDI spillover.

4.3. Control variables

After reading a large number of relevant literature on TFP, this paper selects marketization level (market), industrial structure (industry), human capital status (people), financial development (finance), and foreign trade dependence (trade) as control variables.

4.3.1. Marketization level (market)

TFP is affected by the free flow of production factors and the effective allocation of resources. Referring to the approach of Liao and Wang [15], this paper uses the proportion of state-owned enterprise employees in total employment to measure the level of marketization.

4.3.2. Industrial structure (industry)

This indicator is an important measure of positive development, reflecting the relationship between various production factors within the industry and between industries. Referring to the practices of Fu *et al.* [16] and He [17], this paper uses the proportion of the added value of the secondary industry in GDP to measure the industrial structure and explore its impact on TFP.

4.3.3. Human capital status (people)

Currently, the most authoritative measure of human capital status is years of education. According to China's education system and referring to the approach of Li *et al.* [18], the formula for calculating human capital is as follows:

$$(A1 \times 6 + A2 \times 9 + A3 \times 12 + A4 \times 16) / A5$$

Where A1 = number of people with primary school education, A2 = number of people with junior high school education, A3 = number of people with high school and technical secondary school education, A4 = number of people with college and above education, and A5 = total population aged 6 and above.

4.3.4. Financial development (finance)

Technological progress in the computer, communication, and other electronic equipment manufacturing industries in various provinces is inseparable from funding support. Therefore, the level of financial development is closely related to TFP. Referring to the approach of Yang and Cheng [19], this paper uses the ratio of total deposits and loans of financial institutions to GDP to measure the level of financial development.

4.3.5. Foreign trade dependence (trade)

Foreign trade dependence is an important indicator of economic openness and has a significant impact on TFP. Referring to the approach of Zhang and Min [20], this paper calculates foreign trade dependence using the ratio of total import and export volume to GDP in each province.

4.4. Transformation variables

Referring to relevant literature, this paper selects R&D personnel input (RDren) and R&D funding input (RDqian) to measure the host country's absorption capacity for FDI technology spillovers. Apart from the technological level itself, absorption capacity is also an important influencing factor for the impact of FDI horizontal spillovers on technological progress. R&D personnel and funding inputs are key indicators of technological absorption capacity. When these two indicators exceed a certain value, FDI horizontal technology spillovers may have a nonlinear impact on technological progress. Therefore, this paper directly selects R&D personnel and R&D funding from the

Table 1. Indicator measurement and data sources

Variable	Indicator	Calculation method	Data source
Dependent variable	TFP	Solow residual	Provincial statistical yearbooks, China Fixed Asset Investment Database, China Labor Statistical Yearbook
Independent variable	FDI horizontal spillover	(Foreign capital + Hong Kong, Macao, and Taiwan capital) / Producer Price Index	China Industrial Statistical Yearbook, China Industrial Economic Database
Transformation variable	R&D personnel input	-	China Statistical Yearbook on High-tech Industries, China High-tech Industry Database
	R&D funding input	-	China Statistical Yearbook on High-tech Industries, China High-tech Industry Database
Control variable	Marketization level	Number of state-owned enterprise employees / Total number of employed persons	China Industrial Statistical Yearbook, Provincial Statistical Yearbooks
	Industrial structure	Value-added of secondary industry / Regional GDP	Provincial statistical yearbooks, China Statistical Yearbook
	Human capital level	-	China Population Statistical Yearbook, China Education Database
	Financial development	Total deposits and loans of financial institutions / Regional GDP	Provincial statistical yearbooks, China Financial Database
	Foreign trade dependence	Total import and export volume / Regional GDP	Nanchang Statistical Yearbook, Jiangxi Statistical Yearbook, China Statistical Yearbook

"China Statistical Yearbook on High-tech Industries" as transformation variables. The specific calculation methods and data sources of each indicator are shown in **Table 1**.

5. Empirical analysis and conclusion

5.1. Calculation of TFP

In this section, the Solow residual method is used to calculate the value of TFP. The specific calculation steps and data are as follows:

5.1.1. Calculation of capital stock

Since China does not publicly release data on capital stock, which is a crucial variable for calculating total factor productivity and is highly significant in academic research, scholars often adopt the Perpetual Inventory Method (PIM) proposed by Goldsmith [21] to estimate China's capital stock. The formula under the geometric decline model of relative efficiency is:

$$K_t = K_{t-1}(1-\delta_t) + I_t \tag{1}$$

Where I_t represents the investment in year t, calculated as I_t = fixed asset investment / fixed asset investment price index; δ_t represents the depreciation rate in year t; $K_{t\text{-}1}$ represents the capital stock in year t-1.

5.1.2. Calculation of TFP using Solow residuals

In 1957, Solow [22] introduced the concept of Solow residuals, which has become the most basic, longest-used, and widest-ranging method for calculating TFP. Therefore, this paper employs the capital stock data calculated in the previous section and uses the Solow residual method to calculate the total factor productivity of the computer, communication, and other electronic equipment manufacturing industries in various provinces of China. The calculation method is as follows:

Assuming that the aggregate production function is the Cobb-Douglas production function:

$$Y_{it} = A_{it}K_{it}^{\alpha}L_{it}^{\beta} \tag{2}$$

Where Y_{it} represents the output of province i in year t; K_{it} represents the capital stock of province i in year t; L_{it} represents the labor input of province i in year t; A_{it}

represents the total factor productivity of province i in year t. The superscripts α and β represent the shares of capital and labor income in total output, respectively.

Taking the logarithm of both sides of the above equation:

Formula for calculating TFP:

$$A_{it} = Y_{it}/K_{it}^{\alpha}L_{it}^{\beta} \tag{3}$$

Formula for calculating TFP growth rate:

$$\frac{\Delta A}{A} = \frac{A_{t+1} - A_t}{A_t} \tag{4}$$

At the same time, considering the time error of TFP, the estimation model of TFP is obtained by rearranging formula (1):

$$\ln\left(\frac{Y_{it}}{L_{it}}\right) = lnA_0 + \alpha \ln\left(\frac{K_{it}}{L_{it}}\right) \tag{5}$$

Estimate the parameter α in the above formula, find α and β (β=1–α), and substitute them to calculate TFP and its growth rate, respectively.

Finally, the perpetual inventory method is used to calculate the annual capital stock of each province. Since the fixed asset investment price index for 2020 and 2021 has not been released, this paper refers to Liping Liao's approach and selects the commodity retail price index of each province for conversion.

After obtaining the capital stock data of each province, this paper estimates the parameters α and β in the Solow residual. Here, OLS is used for estimation. Regression of formula (5) using Stata yields α = 0.385 and β = 0.615, and the test results are significant at a 95% confidence interval. Substituting the parameters into the total factor productivity calculation formula gives the annual total factor productivity and total factor productivity growth rate for each province. **Table 2** provides descriptive statistics for the variables.

5.2. Construction of measurement model and threshold regression

5.2.1. Model construction

$$\mathrm{TFP}_{it} = \alpha_0 + \alpha_1 FDI_{it} + \alpha_c contral + \varepsilon_{it} \tag{6}$$

$$\mathrm{TFP}_{it} = \alpha_0 + \alpha_{11} FDI_{it} + \sum_{j=1}^{r} \alpha_{12} FDI_{it} \times g(RD_{ren_{it}}; \gamma_j; c_j) + \alpha_c contral + \varepsilon_{it} \tag{7}$$

$$\mathrm{TFP}_{it} = \alpha_0 + \alpha_{11} FDI_{it} + \sum_{j=1}^{r} \alpha_{12} FDI_{it} \times g(RD_{qian_{it}}; \gamma_j; c_j) + \alpha_c contral + \varepsilon_{it} \tag{8}$$

$$g(q_{it}; \gamma_j; c_j) = \left\{1 + exp\left[-\gamma_j \times \prod_{j=1}^{m}(q_{it} - c_j)\right]\right\}^{-1} \tag{9}$$

Where i and t represent province and time respectively; TFP_{it} denotes the total factor productivity of province i in year t; FDI_{it} represents the level of FDI technology spillover in province i in year t; RD_{ren} and RD_{qian} refer to R&D personnel and expenditure inputs respectively, and control is a set of control variables including marketization level (market), industrial structure (industry), human capital level (people), financial development (finance), and foreign trade dependency (trade); g is a transfer function with a value between 0 and 1; r represents the number of transfer functions; q_{it} is the threshold variable of the transfer function. In this paper, R&D personnel input (RD_{ren}) and R&D expenditure input (RD_{qian}), which measure the absorption capacity of FDI technology spillover, are selected as the threshold variables. γ is the smoothing coefficient of the transfer function, indicating the speed of transition between different regimes in the model. c represents the location parameter, indicating where the transition occurs, and m

Table 2. Descriptive statistics of variables

Variable name	Variable symbol	Sample size	Mean	Standard deviation	Minimum value	Maximum value
Output	Y	525	20007.770	19627.450	1133.270	124719.500
Capital	K	525	414.353	724.820	27.227	7364.660
Labor	L	525	18.573	39.188	0.132	272.344

is the number of location parameters. m generally takes two values, 1 or 2, representing one or two transitions respectively: when m is 1, $q_{it} > c$ represents the high regime, and $q_{it} < c$ represents the low regime; when m is 2, $q_{it} < c_1$ and $q_{it} > c_2$ represent the outer regimes, while $c_1 < q_{it} < c_2$ represents the middle regime.

5.2.2. Descriptive statistics and basic processing of variables

Descriptive statistics of variables: There are significant differences in inter-provincial total factor productivity, and uneven development of regional technological levels. The minimum values of research personnel and expenditure inputs exist as zero, indicating varying degrees of emphasis on high-tech industries among provinces. China should encourage the development of high-tech industries and attach importance to the role of technology in economic development. **Table 3** presents the descriptive statistics of the variables.

Stationarity test: Before conducting regression analysis on panel data, it is necessary to test the stationarity of the data to prevent spurious regressions. Since the selected data is long panel data, the LLC method is used here to test the stationarity of the panel data. As shown in **Table 4**, the LLC stationarity test for the level of financial development passes the 5% significance level test, while the other variables pass the 1% significance level test. All variables in the above table are stationary.

Table 3. Descriptive statistics of variables

Variable name	Variable symbol	Sample size	Mean	Standard deviation	Minimum value	Maximum value
Total factor productivity	TFP	525	3.351936	4.032272	0.1538242	27.93366
FDI horizontal spillover	FDI	525	3.243632	6.489318	0.0001244	40.52153
Research personnel input	RDren	525	1.663373	4.273021	0	39.6547
Research funding input	RDqian	525	54.56245	163.4398	0	1821.861
Marketization level	market	525	0.3450013	0.3797811	0.0280348	1.646197
Industrial structure	industry	525	0.45378	0.0792148	0.158337	0.6147768
Human capital level	people	525	1526.873	785.6644	52.21295	5302.861
Financial development	finance	525	2.864525	1.164575	1.288197	8.131033
Foreign trade dependency	trade	525	0.332906	0.3850565	0.0270732	1.721482

Table 4. Results of stationarity test

Variable	LLC test value	*P*-value	Stationarity
TFP	-2.9104	0.0018 ***	stationary
FDI	-2.3588	0.0092 ***	stationary
market	-8.7878	0.0000 ***	stationary
industry	-2.3767	0.0087 ***	stationary
people	-3.1310	0.0009 ***	stationary
finance	-1.9551	0.0253 **	stationary
trade	-7.9688	0.0000 ***	stationary
RDren	-5.5854	0.0000 ***	stationary
RDqian	-11.1958	0.0000 ***	stationary

Note: *** indicates significance at the 1% level, ** indicates significance at the 5% level.

5.2.3. PSTR regression results and analysis

Nonlinearity test: This test aims to determine whether there is a nonlinear effect between FDI horizontal technology spillover and technological progress in the industry. The null hypothesis of this test is $\gamma = 0$, which indicates a linear relationship between the two and is not suitable for PSTR regression. The alternative hypothesis is $\gamma \geq 1$, suggesting a nonlinear relationship and further investigation using PSTR. In this paper, three methods, namely Wald, Fischer, and LRT, are employed for testing, with test values denoted as LM, LMF, and LRT respectively. The results presented in **Table 5** indicate that all three test statistics for Model (7) reject the alternative hypothesis at the 1% significance level, confirming the presence of a nonlinear relationship in the model. In other words, R&D personnel input serves as a threshold variable for the nonlinear relationship between FDI horizontal technology spillover and technological progress. However, for Model (8), under both $m = 1$ and $m = 2$ scenarios, the statistical values of the three test results are not significant, failing to reject the null hypothesis. This suggests that R&D expenditure input does not cause a nonlinear relationship between FDI horizontal technology spillover and technological progress. The reason may be that the industry in China has fully utilized funding, and issues such as corruption due to excessive funding input do not arise, thereby not leading to a nonlinear relationship between FDI horizontal technology spillover and technological progress. This result aligns with the actual situation, but further research is needed to determine whether regions with different levels of economic development yield similar findings. Since the continuous input of R&D expenditure does not affect the promotional effect of FDI horizontal technology spillover on technological progress, there exists a linear relationship between FDI horizontal technology spillover and technological progress under the condition of continuous R&D expenditure input. The following section further explores the nonlinear correlation between FDI horizontal technology spillover and technological progress in the industry, considering R&D personnel input.

Table 5. Results of nonlinearity test

m = 1	**Model 8**		**Model 9**	
	Statistic	***P*-value**	**Statistic**	***P*-value**
LM	7.556	0.006	2.893	0.089
LMF	7.286	0.007	2.765	0.097
LRT	7.611	0.006	2.901	0.089
m = 2	**Statistic**	***P*-value**	**Statistic**	***P*-value**
LM	7.725	0.021	2.901	0.234
LMF	3.719	0.025	1.384	0.252
LRT	7.782	0.020	2.909	0.233

Remaining nonlinearity test: The purpose of the remaining nonlinearity test is to determine the optimal number of transfer functions, i.e., the value of r, under different m values. The null hypothesis of this test is $r = 1$, indicating that the model only contains one transfer function; the alternative hypothesis is $r = 2$, suggesting the presence of two transfer functions in the model. For the test of Model (7), as shown in **Table 6**, the statistical values of the three test results are not significant when $m = 1$ and $m = 2$, failing to reject the null hypothesis of $r = 1$. Therefore, Model (8) only includes one transfer function.

Table 6. Results of remaining nonlinearity test

m = 1	**Model 8**	
	Statistic	***P*-value**
LM	0.027	0.870
LMF	0.025	0.873
LRT	0.027	0.870
m = 2	**Statistic**	***P*-value**
LM	0.263	0.877
LMF	0.124	0.883
LRT	0.263	0.877

Determination of location parameters: This section focuses on determining the number of location parameters in the model, i.e., determining the value of m. The value of m is generally 1 or 2. Here, the AIC (Akaike Information Criterion) and BIC (Bayesian Information

Criterion) minimization criteria are used to determine the value of m. As shown in **Table 7**, both AIC and BIC have smaller values when $m = 1$ compared to when $m = 2$. Therefore, the optimal number of location parameters m for this model is 1.

Table 7. Results of determining the number of location parameters

Location parameters	Model 8	
	$m = 1$	$m = 2$
AIC	2.136	2.142
BIC	2.169	2.182

PSTR regression analysis: Based on the previous tests, it is known that Model (7) exhibits a nonlinear relationship with one transfer function ($r = 1$) and an optimal number of location parameters ($m = 1$), while Model (8) does not show a nonlinear relationship. In this section, MATLAB is used to perform PSTR regression analysis on Model (7).

As shown in **Table 8**, with R&D personnel input as the threshold, there is a nonlinear correlation between FDI horizontal technology spillover and technological progress in the computer, communications, and other electronic equipment manufacturing industry. As the investment in R&D personnel increases, the industry's technological absorption capacity gradually improves. Consequently, FDI horizontal technology spillover promotes industry technological progress through competition effects and other pathways. However, after the continuous investment in R&D personnel exceeds a certain level, FDI horizontal technology spillover can hinder industry technological progress.

The goal of continuous investment in R&D personnel, beyond a certain level, is to cultivate high-tech talents capable of independent innovation. The cultivation of relevant talents is a long-term process with relatively slow impacts [23], making it difficult to enhance the current stage of technological absorption capacity. A significant amount of FDI spillover is not immediately absorbed, leading to a situation where, beyond the threshold, FDI horizontal spillover hinders the technological progress of the industry.

5.2.4. Threshold crossing situation in different regions

Eastern region: For both Model (7) and Model (8), $r = 1$ and $m = 1$, indicating that both models have one transfer function and the optimal number of location parameters is 1 (**Tables 9** and **10**). In the case of the eastern region, the impact of FDI horizontal technology spillover on the technological progress of the industry is nonlinear. This nonlinearity is further explored using two indicators that measure technological absorption capacity: R&D personnel input and R&D expenditure input as thresholds. The specific nonlinear relationship can be studied through the PSTR model.

Central region: As shown in **Table 11**, none of the three tests for both models are significant when $m = 1$ and $m = 2$, indicating that the PSTR model is not suitable in

Table 8. PSTR regression results

	Variable	Coefficient	Estimated value	*T*-value
Linear part	FDI	α_{11}	0.3795 * (0.0591)	6.4197
Nonlinear part	FDI	α_{12}	-0.2699 * (0.0524)	-5.1505
Location parameter	c		4.5458	
Smoothing parameter	γ		5.4072	
Akaike information criterion (AIC)	AIC		2.136	--
Bayesian information criterion (BIC)	BIC		2.169	
Sum of squared residuals	RSS		4335.714	

Table 9. PSTR regression results for model (7)

	Variable	Coefficient	Estimated value	*T*-value
Linear part	FDI	α_{11}	0.3167 * (0.0573)	5.5286
Nonlinear part	FDI	α_{12}	-0.2125 ** (0.0493)	-4.3089
Location parameter	c		4.5883	--
Smoothing parameter	γ		6.2317	
Akaike information criterion (AIC)	AIC		0.468	
Bayesian information criterion (BIC)	BIC		0.532	
Sum of squared residuals	RSS		315.060	

Table 10. PSTR regression results for model (8)

	Variable	Coefficient	Estimated value	*T*-value
Linear part	FDI	α_{11}	0.2199 ** (0.0440)	4.9987
Nonlinear part	FDI	α_{12}	-0.1043 ** (0.0321)	-3.2501
Location parameter	c		2.1988	--
Smoothing parameter	γ		25.4037	
Akaike information criterion (AIC)	AIC		0.553	
Bayesian information criterion (BIC)	BIC		0.616	
Sum of squared residuals	RSS		332.893	

Table 11. Results of nonlinearity test for the central region

***m* = 1**	**Model (7)**		**Model (8)**	
	Statistic	***P*-value**	**Statistic**	***P*-value**
LM	0.255	0.614	0.715	0.398
LMF	0.242	0.624	0.679	0.411
LRT	0.255	0.613	0.716	0.397
***m* = 2**	**Statistic**	***P*-value**	**Statistic**	***P*-value**
LM	0.417	0.812	1.286	0.526
LMF	0.196	0.822	0.610	0.545
LRT	0.417	0.812	1.291	0.524

this case. In other words, for the central region, there is no nonlinear correlation between FDI horizontal technology spillover and technological progress in the industry.

The reason may be that the central region has relatively less investment in R&D personnel and expenditure, and competition effects, human capital flow effects, etc., have not yet reached the threshold level that would make the relationship nonlinear.

Western region: Similar to the central region, in the western region, the relatively insufficient investment in research and development is not enough to reach the threshold value that causes nonlinearity between the two (**Table 12**).

Table 12. Results of nonlinearity test for the western region

m = 1	Model (7)		Model (8)	
	Statistic	*P*-value	Statistic	*P*-value
LM	0.670	0.413	0.166	0.684
LMF	0.637	0.426	0.157	0.693
LRT	0.672	0.412	0.166	0.684
***m* = 2**	**Statistic**	***P*-value**	**Statistic**	***P*-value**
LM	9.132	0.100	2.559	0.278
LMF	4.571	0.120	1.222	0.298
LRT	9.429	0.900	2.581	0.275

5.2.5. Analysis of technological progress pathways: Independent innovation and FDI technology spillover

Technological progress primarily relies on independent innovation and FDI technology spillover. As demonstrated by the empirical results in the eastern region, when investment in research and development personnel and expenditure is excessive, FDI horizontal technology spillover does not significantly promote technological progress. Due to the dual nature of independent innovation [24], scientific research investment in the industry is directed towards enhancing independent innovation capabilities. This process has a long cycle and does not significantly promote technological progress. In this stage, an increase in FDI horizontal technology spillover does not facilitate technological progress. In the long run, improving independent innovation capabilities can enable China to break free from foreign technology monopolies. For a country to truly achieve technological progress, independent innovation is the best pathway. To absorb a significant amount of FDI horizontal technology spillover, the host country is bound to enhance its technological absorption capabilities. This enhancement not only improves the ability to absorb but also boosts independent innovation capabilities. An increase in FDI horizontal technology spillover drives the technological progress pathway of the host country from relying on technology spillover to independent innovation.

6. Conclusion and policy suggestions

6.1. Research conclusion

Based on panel data from the computer, communications, and other electronic equipment manufacturing industries in 25 provinces in China from 2001 to 2021, this paper employs the Panel Smooth Transition Regression (PSTR) model using MATLAB to investigate the impact of FDI horizontal spillover effects on technological progress in the industry, with R&D expenditure and R&D personnel input as transition variables. The following conclusions are drawn from both national and regional perspectives:

Firstly, FDI horizontal technology spillover promotes technological progress in the industry, but when R&D personnel input exceeds a threshold, FDI horizontal technology spillover hinders technological progress in the industry.

Secondly, in the eastern region, FDI horizontal technology spillover promotes technological progress in the industry. However, when both R&D expenditure and R&D personnel input exceed their respective thresholds, FDI horizontal technology spillover hinders technological progress. In the central and western regions, there is a linear relationship between FDI horizontal technology spillover and technological progress in the industry.

6.2. Policy suggestions

Based on the above research findings, this paper proposes the following suggestions:

For the government: Firstly, from a national perspective, provincial governments, especially in the eastern region, should pay attention to investing appropriate amounts and improving the utilization efficiency of R&D investment to prevent low utilization efficiency.

Secondly, the process of cultivating independent innovative talents should be accelerated. Technological progress cannot rely solely on FDI spillovers. Besides utilizing the human capital flow effect generated by foreign capital inflows, domestic independent research and development should become the main pathway, deepening the strategy of strengthening the country through science and technology.

Thirdly, when making R&D investments in the eastern region, attention should be paid to the amount of investment to prevent situations where excessive R&D investment hinders technological progress in the industry due to FDI horizontal technology spillovers.

Fourthly, the central and western regions should strengthen their economic development and increase R&D investment. According to technology diffusion and human capital theories, sustained R&D investment in these two regions will positively impact the phenomenon of FDI horizontal technology spillovers promoting technological progress in the industry.

For enterprises: Firstly, from the perspective of enterprises, they should invest in R&D according to their capabilities. More R&D investment is not always better. When FDI generates horizontal spillovers, excessive R&D investment can hinder technological progress, especially for enterprises in the eastern region. Enterprises should evaluate their technological absorption capabilities before deciding whether to continue increasing R&D investment.

Secondly, when deciding whether to make direct investments, foreign investors should not only consider the economic strength of the host country but also focus on the technological spillover absorption capabilities of host country enterprises. Absorption capability should become a key factor in foreign investors' decision-making. Countries lacking absorption capabilities may not be able to utilize the potential benefits brought by foreign capital, while countries with higher absorption capabilities are more likely to fully absorb and benefit from foreign direct investment, generating positive feedback. Therefore, foreign investors should prioritize absorption capabilities during their investigations.

Disclosure statement

The authors declare no conflict of interest.

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A Spiral Learning Model for Computer Practical Education Based on Multidimensional Practice

Xiaolin Zhao*, Jingfeng Xue, Yong Wang, Fengnian Zhao, Tianyu Huang, Shuoying Chen
School of Computer Science, Beijing Institute of Technology, Beijing 100081, China

***Corresponding author:** Xiaolin Zhao, zhaoxl@bit.edu.cn

Abstract:

In view of the problem that the cultivation of practical skills in computer education in universities is mainly focused on course assignments or ordinary practical courses, and has not formed a partial order skill progression like the theoretical course group, this paper proposes a spiral learning model for computer education based on multidimensional practice. This model takes the "craftsmanship spirit" as the core of the ideological and political construction of the integration of industry and education, and "ideological and political guidance, problem orientation" as the characteristics of the course group. It expounds on how to construct a multidimensional practical spiral model through the internal circulation of the course with the learning method of "explaining, doing, demonstrating, and improving," and the ascending external circulation among different grades with the learning objectives of "mastering, understanding, researching, and innovating." Finally, the teaching effect is illustrated through the evaluation of teaching data in the past three years, and suggestions for continuous improvement are provided.

Keywords:

Computer practical teaching
Multidimensional practice
Spiral learning
Explaining, doing, demonstrating, and improving
Mastering, understanding, researching, and innovating

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1. Introduction

Currently, computer networks have penetrated deeply into people's lives. Smartphones have become internet terminals, smart homes and robots are realizing scenes from science fiction movies, and health codes are assisting in the fight against pandemics. All of these are inseparable from the labor of "code farmers." However, the work of "code farmers" is not limited to the coding process. It involves more software design, testing, and higher-level research, development, and innovation. This requires undergraduate computer education in universities to focus not only on coding practical abilities but also on enhancing feedback and improvement from practice to theory. The training mode of computer talents has always been the focus of teaching and research for university teachers [1]. In recent years, innovative talent training has become the main direction of teaching research [2]. However, in current university computer education, most practical ability improvement channels are through course practices [3] or separate practical courses [4]. These focus on improving horizontal abilities within the course but lack the joint application of vertical course knowledge and progressive practical goals. There are still deficiencies in students' progressive computer ability improvement, which can cause bottlenecks in their practical ability improvement and prevent them from receiving "innovation incentives." This, in turn, can affect the improvement of abilities within the course and make it difficult to achieve deeper ideological and political goals [5]. To address this issue, as a double first-class university, we attempt to integrate three years of vertical practical courses to form a multidimensional practical spiral model of computer education, consisting of an intra-course cycle with an "explaining, doing, demonstrating, and improving" learning approach and an extra-course ladder with "mastering, understanding, researching, and innovating" learning objectives.

2. Spiral learning model of computer education based on multidimensional practice

The spiral learning model based on multidimensional practice is shown in **Figure 1**. This model is not targeted at a single course, nor is it limited to practical courses. It is a condensation and refinement of four years of undergraduate practical education.

This model directly involves four practical courses across three academic years, including the second-year courses "Basic Training in Internet Application Development" and "Basic Training in Software Engineering," each worth 1.5 credits; the third-year course "Comprehensive Practice in Software Engineering," worth 3 credits; and the fourth-year course "Professional Training in Software Engineering," also worth 3 credits. Each course spans three weeks, totaling 9 credits. The theoretical foundation of these four practical courses is derived from a year of theoretical courses taken by the students, covering the main knowledge system of computer education. The main thread of the spiral model is "ideological and political guidance, problem orientation," which constructs the framework of the spiral learning model. "Explaining, doing, demonstrating, and improving" constructs the spiral learning process, while "mastering, understanding, researching, and innovating" builds a progressive evolution of abilities layer by layer. The combination of these three enriches the connotation of the spiral learning model.

(1) We use ideological and political guidance to drive learning motivation and build a new channel for ideological and political construction, guiding students to practice the "craftsmanship spirit," "contract spirit," and "initiative spirit." We orient learning progress around problems, following the principle that "practice is the only criterion for testing truth." Through analyzing and solving problems, we conduct scientific research exploration, implementing ideological and political education in the classroom [6]. Software design and programming implementation are also forms of labor, and the craftsmanship spirit is primarily a labor spirit. We establish a sense of mission to serve the country through software, and through careful guidance and strict requirements, we complete project tasks with high quality, practicing the

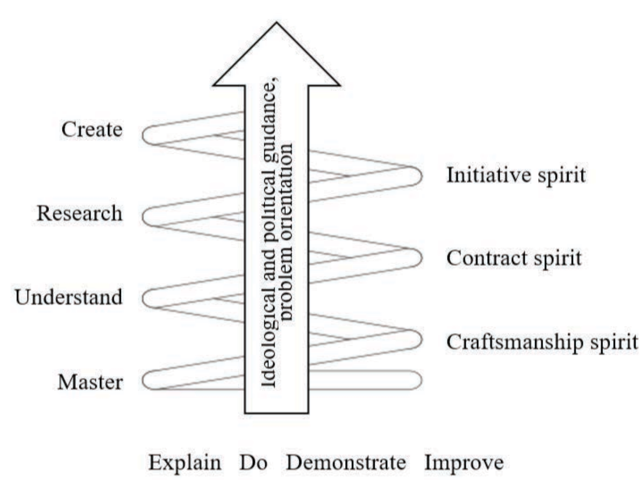

Figure 1. Spiral learning model

dedication, meticulousness, and excellence of the craftsmanship spirit.

(2) Each layer of the spiral learning model constructs the learning process according to "explaining, doing, demonstrating, and improving," and different layers progressively advance according to "mastering, understanding, researching, and innovating," forming a spiral, three-dimensional, and progressively ascending learning model. In this model, each practical course is both a comprehensive practical test of the theoretical learning from the previous year and an incentive to guide students' learning in the following year. By longitudinally connecting multiple practical courses across three academic years, we have constructed a spiral learning model and practical curriculum system suitable for the undergraduate stage of research-oriented universities, enabling multiple courses to form a progressive relationship in content and ability.

(3) Through the implementation of the spiral learning model and practical curriculum system, we adopt a horizontal cyclic teaching process control of "explaining, doing, demonstrating, and improving" and a vertical progression of abilities through "mastering, understanding, researching, and innovating." Students conduct research in practice and innovate from research, cultivating the "initiative spirit."

It should be emphasized that the horizontal and vertical aspects of this spiral model are inseparable and integral parts. They are the flesh and blood of the spiral model, and every aspect requires careful design and implementation.

3. Building an ideological and political construction channel for the integration of industry and education with "craftsmanship spirit" as the core

Scientific research practice is a practical activity guided by theory, and it necessarily requires a spirit throughout the process. Combining the "practical labor" characteristics of practical courses, we carefully design the evaluation of labor for second, third, and fourth-year students [3], and propose an ideological and political construction channel with "craftsmanship spirit" as the core, forming a distinctive feature of "ideological and political guidance, problem orientation."

The "craftsmanship spirit" is first and foremost a labor spirit. Relying on the educational concepts of OBE [7] and CDIO [8], as well as the requirements of engineering education certification [9], we view computer practical activities as a form of labor. Engels pointed out that "real labor...begins with the manufacture of tools." The manufacture of tools is the problem addressed in computer practical courses. The second-year practical courses focus on using existing tools for labor, such as building websites; the third-year practical courses imitate the manufacture of tools, such as developing compilers; and the fourth-year practical courses involve creating new tools, such as analyzing network protocols and traffic to measure network security status. Through the design of course learning objectives and labor processes, we help students understand the characteristics of engineering education [10], explore professional development directions, reflect on professional missions, establish lofty aspirations to serve the country through software, stimulate students' enthusiasm for learning and labor, and cultivate top talents [11].

The "craftsmanship spirit" embodies the dedication and initiative spirit of professional labor. In the second-year practical courses, we guide students to understand the current gaps and urgent needs of China's software industry, advancing their cognition of software understanding. The third-year practical courses raise questions targeting the weak links of China's basic software, guiding students to join the pursuit, such as designing and implementing small databases and comparing them with domestic and foreign commercial databases. The fourth-year practical courses focus on innovation, transforming the university's scientific research platform into a teaching innovation platform [12], combining innovation with dedication to form the driving force for students' efforts.

The "craftsmanship spirit" represents a meticulous and excellence-seeking contract spirit. Emphasizing details and pursuing perfection are key elements of the "craftsmanship spirit" and manifestations of engineering capabilities [13]. Through the signing of classroom written contracts, quantifiable and evaluable agreements are formed in terms of labor objectives (project goals), time requirements, funding, software functionality, and performance. In the evaluation of practical courses, the perfection of software is assessed through details such as software human-machine interfaces, interfaces, boundary value testing, functional stability, and computational efficiency. Team collaboration and engineering management are evaluated based on research and development models, process management, document preparation, teacher-student interaction, budgeting and final accounting, software demonstration, and promotion [14]. This makes the "craftsmanship spirit" a spiritual pillar for software engineering to transition from a "craft" to an "industry."

"Ideological and political guidance, problem orientation" helps students open the door to scientific research, stimulates creative thinking, and cultivates innovative talents. Scientific theoretical learning and engineering practice are reflected through a spiral practical process. Practical topics are selected based on tasks directly related to national and social needs, introducing research tasks that align with university characteristics. A problem-oriented teaching model is implemented [15], establishing a new ideological and political model that cultivates students' sense of mission toward professional cognition and their sense of responsibility towards acquiring independent intellectual property rights for significant basic software.

4. Constructing the "explaining, doing, demonstrating, and improving" intra-course learning process

"Explaining, doing, demonstrating, and improving" is a complete intra-course learning cycle implemented in each course. While the objectives of "explaining, doing, demonstrating, and improving" may vary across courses, the adopted approach is similar. A complete cycle of "explaining, doing, demonstrating, and improving" includes four processes: course design, strategy, teaching practice, and evaluation, as shown in **Figure 2** [16].

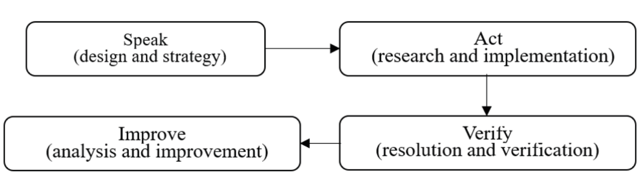

Figure 2. The four processes of "explain, do, demonstrate, improve"

Taking the senior year software engineering professional training course as an example, the work of these four stages is as follows:

(1) Be able to complete the practical process of software engineering projects, write various software engineering documents, and evaluate them. During the practical process, conduct scientific research on complex software engineering problems, demonstrating basic scientific research quality and ability (explain).

(2) To achieve the above goals, students should complete and submit tasks including requirements analysis, system design (incorporating software engineering methods), software development (incorporating new technology learning), the entire process of system testing, and promotion (English presentation). Based on the topic, students must conduct a series of scientific research processes such as researching materials, discussion and analysis, system modeling, and problem-solving, and submit a research report. The guidance process focuses on cultivating students' exploratory spirit, scientific thinking, practical ability, and innovative ability. Practical teaching should not only impart experimental skills and operational abilities, but also be positioned as systematic imparting and learning training of experimental science and skills, as well as practical and innovative abilities (do).

(3) Through the collection and analysis of student submissions, it is confirmed that students have completed the general process of complex software engineering development, can write software engineering documents, and can perform practical work such as requirements analysis and pattern design. Through research and analysis, students propose their own solutions to the problems existing in the research process (self-study, referring to the latest relevant theoretical research results), analyze individual student situations and overall scores, and make longitudinal comparisons with previous teaching situations (demonstrate).

(4) By analyzing student homework and research

reports, longitudinally comparing the teaching process, scores, teaching deficiencies, and countermeasures of the previous session, the current teaching process is timely revised, and deficiencies in the current teaching process are analyzed. Improvement strategies for the next time are provided in three aspects: theoretical mastery, complex software development, and related theoretical research (improve).

The above four processes constitute a cycle, continuously improving the quality of the course in a spiral manner. By designing the complete process of "explain, do, demonstrate, improve" for each expected learning outcome, and continuously adjusting it based on actual situations during implementation.

To encourage students to conduct research and innovate, they are allowed to apply for innovation scores based on the originality and novelty of their research results, which will be counted as part of the total course score.

In the design of the "explain, do, demonstrate, improve" feedback standards, apart from emphasizing the three major feedback questions ("Where am I going?," "How do I get there?," and "Where to next?"), the following principles are also followed: (1) Feedback focuses on tasks rather than students; (2) Provide well-designed feedback that describes "what," "how," and "why"; (3) Feedback information is specific and clear, directly changing the performance evaluation criteria; (4) Feedback should be as simple and objective as possible, integrating feedback from both instructors and students; (5) Emphasize immediate feedback for low-achieving students and delayed, innovative feedback for high-achieving students.

5. Constructing a spiral learning model of "master, understand, research, innovate" across courses

"Master, understand, research, innovate" is a requirement for students' abilities designed according to their year of study (as shown in **Figure 3**). Each course mainline adopts case-based teaching, with specific methods varying among courses. The sophomore-level courses on basic training in internet application development and software engineering require students to transition from "master" to "understand" abilities. The junior-level course on comprehensive software engineering practice requires students to transition from "understand" to "research" abilities. The senior-level course on software engineering professional training requires students to make the transition from "research" to "innovate" abilities.

5.1. "Master" to "understand"

The meaning of "master" to "understand" is the transition from being able to program to understanding software, with the targeted career being an engineer. Students have completed learning C language in their first year of college and can "master" programming, but they lack an overall concept of software. The meaning of "understand" is to grasp the basic structure of software, understand basic software design methods, and comprehend the basic uses of software.

Basic Training in Internet Application Development guides students to design and develop an Internet application, covering knowledge areas such as the basic structure of the Internet, website structure, CSS, JavaScript, HTML5, and Android. This allows students

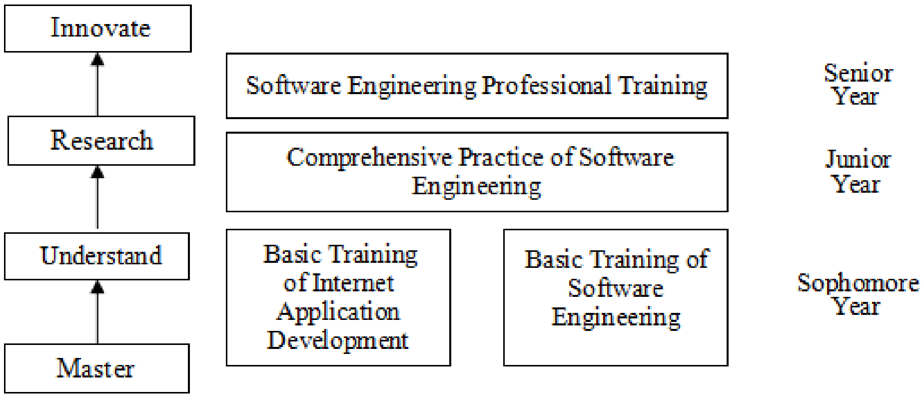

Figure 3. "Master, understand, research, innovate" ascension diagram

to gain a preliminary understanding of the Internet, software architecture, and the software design process from a macro perspective. Basic Training in Software Engineering introduces students to new technical topics, including data, intelligence, networking, and graphic visualization, and guides them to complete comprehensive project selections based on their personal interests. This helps students to gain an initial understanding of software engineering and comprehend the software engineering process. By adopting case-based teaching and a multi-task-driven approach, students are encouraged to transition from autonomous needs (the "master" software stage) to competency needs (the "understand" software stage).

To address the issues faced by these two courses, such as the simplicity of the content, limited class hours, and the large number of students, which make it difficult to stimulate interest in learning, provide sufficient class hours, and offer personalized teaching, we have rebuilt the teaching content. The teaching content consists of three parts: strengthening programming, practical areas, and understanding software. The courses introduce advanced technologies and multi-domain software technologies, including big data, artificial intelligence, virtual reality, etc., guiding students to shift their focus from programming-related case studies to practical application-oriented software engineering. The result is that students "understand" the basic process of software development and expand their knowledge system.

5.2. "Understand" to "research"

The meaning of "understand" to "research" is the transition from understanding software to researching software, conducting research in practice, with the targeted career being a scientific researcher. After completing the "understand" training, students begin to learn professional courses in their second year of college and start to understand the basic principles of computers and software from a theoretical perspective. However, there is a huge gap between theory and implementation, which requires research.

The Integrated Practice Course in Software Engineering, offered in the third year, allows students to learn new knowledge and research specific problems through means such as literature study, while integrating professional course knowledge. The topics mainly address the shortcomings of China's three major basic software areas. The related knowledge involved in the course projects, such as "Compilation Principles," "Operating System Principles," and "Database Principles," are all content that will be learned in subsequent courses.

For example, a topic like a C-language-like interpreter requires an understanding of C language's operational rules and basic programming principles (the "understand" software stage). However, knowledge such as the QT development environment and debug principles are not covered in regular college courses. These knowledge points require students to quickly learn independently based on project requirements. To complete the interpreter, students need lexical analysis and syntax analysis from "Compilation Principles," which involves theoretical exploration (the "research" stage). This enables students to comprehensively apply the basic theories of software engineering and computer knowledge, organically integrating theoretical guidance with development practice, combining engineering goals with independent innovation, and effectively coordinating personal strengths with team collaboration. Through internships, students cultivate a pragmatic mindset, a down-to-earth work style, and meticulous engineering abilities, achieving the goal of combining theory with practice and integrating engineering with innovation.

5.3. "Research" to "innovate"

The meaning of "research" to "innovate" is to innovate from research, targeting the career of a scientist. The Software Engineering Professional Training course has two threads. One is to formally complete projects in practice according to software engineering methods, and the other is to closely follow national strategic needs and innovate in research in terms of content. For example, combining the cutting-edge research directions of cyberspace security and big data, a topic such as "Windows Malicious Code Classification Based on Machine Learning" is given. This requires selecting appropriate features and classification algorithms based on the static analysis results of given samples (research stage), implementing the classification of given codes, and making necessary improvements to the algorithm based on specific datasets (innovation stage).

For the first thread, the course explains the background knowledge of application fields, completes the requirements analysis of complex software systems, completes the software engineering project practice process in terms of results, writes various software engineering documents, and evaluates them. In the process of practice, scientific research is conducted on complex software engineering problems, completing the general scientific research process and exercising students' basic scientific research quality and ability. The course emphasizes process management, involving team setting, project management, and economic decision-making. It encourages innovation, involving technological innovation, scientific research, and engineering innovation, and sets up a dedicated innovation score. A software engineering process plan needs to be developed, and the training and research process should have a clear plan that can be accurate to the day and retain redundancy. Appropriate software process tools are used to support training and research work, meeting project management requirements.

For the second thread, the topics for practical training come from teachers' vertical scientific research tasks, closely following major national needs (such as the National Key Research and Development Program and the National Natural Science Foundation of China projects) and the latest cutting-edge technologies (such as network security, artificial intelligence, big data, and digital media). Fragments with more practical links are extracted to form relatively complete research topics. Firstly, the topics should meet the basic requirements of the course content and the requirements of complex software engineering problems. Secondly, they should have a certain level of difficulty to stimulate students' enthusiasm, and it should be confirmed that they can be basically completed during the short semester. The research can be theoretical or technical, but it must be carried out with practice as the carrier and practical training as the result. Finally, through the combination of form and content, an innovative environment for students is provided, and students are encouraged to think with a "pioneering" spirit in practice through the encouragement of innovation scores.

In this way, there are innovation scores in the form of research practice, and innovation determines whether a student's performance is excellent or good. In terms of the content of research practice, closely following major national needs (such as the National Key Research and Development Program and the National Natural Science Foundation of China projects) and the latest cutting-edge technologies (such as network security, artificial intelligence, big data, and digital media) ensures the practical value and originality of innovation.

6. Evaluation of teaching effectiveness and continuous improvement of the spiral model

6.1. Evaluation of teaching effectiveness

The courses involved in this achievement have been running for four years according to this spiral learning model, with nearly 1,000 students participating. Among them, over 300 students from two grades have experienced a complete spiral learning model, while the remaining students have completed one or two cycles.

Based on the analysis of graduation project topics in the past three years, the proportion of students choosing theoretical research has increased from 24% to 35%. The analysis of dissertations shows that the percentage of students demonstrating innovation has risen from 24% to 40%, indicating the positive impact of this achievement on research and innovation. In terms of plagiarism checks, the proportion of dissertations with a repetition rate exceeding 20% has dropped rapidly from 20% to 8%, suggesting that the "craftsmanship spirit" has subtly influenced students.

Over the past three years, the curriculum system's OBE support scores (with a maximum score of 1) have been above 0.8 for all items, with scores related to research practice activities averaging around 0.85. This indicates stable cultivation of students' practical abilities without being affected by scientific research training and innovation. The high research scores reflect improved scientific research capabilities among students, achieving the curriculum system's goal of integrating research into practice and fostering innovation through research. In terms of practical results, each teaching activity generates over 1GB of research practice documents and codes, forming a valuable accumulation for the learning model.

After completing the comprehensive spiral learning model training, students' overall abilities have significantly improved. Some students have even discovered their research interests and begun participating in scientific research work in teachers' laboratories. Often, they can determine their research direction for their master's degree after completing the practical courses in their fourth year. Those who are recommended for postgraduate studies actively contact their mentors to start their graduation project tasks and postgraduate research topics ahead of time.

6.2. Continuous improvement

The "explain, do, demonstrate, improve" approach represents a wave-like spiral progression, while the "master, understand, research, innovate" methodology reflects a spiral ascension through negation. Combining these two approaches constitutes the spiral learning model. This model is formally a result of the continuously increasing demands of practical courses at research universities and is essentially an inevitable outcome of philosophical guidance on natural science methodologies.

The model, which currently only tracks until graduation design, cannot yet fully illustrate the extent of improvement in students' innovation abilities. This will be analyzed and continuously improved in subsequent educational reform practices. The model also faces the requirement of its own continuous improvement, necessitating both horizontal learning process enhancements and vertical connectivity improvements. Starting from observing teaching details, careful adjustments to course schedules and case studies, as well as the introduction of new tools and methods, are essential. This approach aims to drive technological, teaching, theoretical, and scientific advancements through a two-way feedback spiral of continuous improvement.

7. Conclusion

Ideological and political guidance is the essential connotation of the practical curriculum system, while the "craftsmanship spirit" serves as its guiding principle. Problem orientation lays the foundation for the curriculum system, scientific research training constitutes its methodology, and innovative practice represents its ultimate goal. These elements—ideological and political guidance, problem orientation, practice, scientific research, and innovation—form the core components of the curriculum system and establish the framework for an innovative practical curriculum system.

Spanning three academic years, the curriculum system aids in guiding students to deepen their theoretical course learning and consciously expand their knowledge structure. It also lays a solid foundation of practical abilities for students' graduation projects and postgraduate innovation. The model's innovativeness lies in its ability to guide students toward self-improvement through a spiral ascension model, embodying the "spirit of labor." It emphasizes that "teaching someone to fish is better than giving them a fish," forming an operable practical system with innovation ability cultivation as the overarching goal of practical results. This approach aims to guide students from the "realm of necessity" to the "realm of freedom" in their practical thinking, potentially serving as a valuable reference for practical education in other disciplines.

Disclosure statement

The authors declare no conflict of interest.

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Exploration of the Design and Implementation Mode of a Comprehensive Ideological and Political Model in the Computer Network Course

Xiaoming Zhang*, Shibo Zhang, Fang Wang, Fei Yang, Weiwei Wang
School of Information Engineering, Beijing Institute of Petrochemical Technology, Beijing 102617, China

***Corresponding author:** Xiaoming Zhang, zhangxiaoming@bipt.edu.cn

Abstract:

Based on literature research and according to the trinity goals of knowledge, skill, and value in the computer network course, this paper proposes a comprehensive ideological and political model for the computer network course. It explores how to integrate five ideological and political elements: the exploratory spirit of new network technologies, the sense of mission to serve the country through the network, the craftsmanship spirit of network design, network security and legal awareness, and the innovative consciousness of network design. Based on the reconstruction of teaching content and the development of teaching resources, this paper elaborates on the key points of implementing five modes of ideological and political integration: teaching content, teaching resources, practical teaching, classroom flipping, and network project development. Finally, through six assessment methods including online learning, in-class tests, experimental teaching, special reports, extracurricular assignments, and final exams, the effectiveness of ideological and political teaching in the course is demonstrated.

Keywords:

Computer Network
Course objectives
Comprehensive
Ideological and political elements
Teaching design
Evaluation

Online publication: December 27, 2024

1. Introduction

Integrating ideological and political education into computer network courses can effectively address the issues of traditional ideological and political education, such as insufficient radiation, acceptance, and influence. Simultaneously, it enables students to distinguish truth from falsehood and establish correct values. In the study by Wang *et al.* [1], "socialist core values" are regarded as the content supply for ideological and political education in courses and matched with concepts in the field of computer networking, providing two examples of teaching plans. Zhang *et al.* [2] summarized the target framework of ideological and political education in network courses into four main aspects: political theory, national consciousness, fighting spirit, and network ethics, and elaborated on the entry points of course knowledge and ideological and political elements in teaching. Fan *et al.* [3] explored the relationship between course knowledge and ideological and political education. In Jiang's study [4], an educational planning table for ideological and political education in computer network courses is established, focusing on introducing three key ideological and political aspects: loving the party and the country, dedication to work, and abiding by laws and regulations. Based on the background of professional group construction, Li [5] proposed a target framework for ideological and political education in courses, including three levels: national, social, and individual. On this basis, it elaborates on the correspondence between the key points of each chapter's knowledge and the entry points of ideological and political education. Cheng and Xu [6] established entry points and elements for ideological and political education in courses based on nine network knowledge areas. Additionally, scientific career planning [7] can also help students establish long-term goals. China's Huawei Technologies Co., Ltd. occupying the world's largest share of the core router market demonstrates the significant enhancement of China's independent innovation capability.

In summary, existing literature has focused on studying the goals and educational entry points of ideological and political education in courses, introducing many examples in terms of network power and network security. However, there are several common deficiencies: the ideological and political elements in courses tend to emphasize theoretical teaching methods and are relatively lacking in other teaching approaches; the effects of ideological and political education in computer network courses are mostly qualitative descriptions and are not integrated into course objective evaluations. Analyzing these reasons, firstly, the course objectives are not precise enough, and ideological and political elements are not uniformly designed as basic elements of talent training objectives, which cannot correspond to the teaching activities and assessment methods that the course should have, affecting qualitative and quantitative evaluations. Secondly, ideological and political elements are not combined with the thematic content and characteristics of the courses being taught, but simply and repetitively apply other ideological and political cases, making it difficult to implement them into specific practical activities and affecting the implementation effect.

To address the integration and evaluation issues of ideological and political education in courses, a comprehensive integration approach is adopted: starting from the design of course objectives through top-level planning, integrating ideological and political education into the course; integrating ideological and political education into course construction and various teaching links; and integrating ideological and political education into the multi-faceted assessment methods of the course.

2. Optimal design of computer network course objectives

Computer networks are one of the core courses in China's computer science and technology program and are among the four courses in the comprehensive examination for national postgraduate entrance examinations in computer science and technology. Besides meeting the requirements of computer science majors and postgraduate entrance examinations, the design of its teaching objectives can vary greatly depending on the school's positioning and professional training goals.

2.1. Analysis of course nature

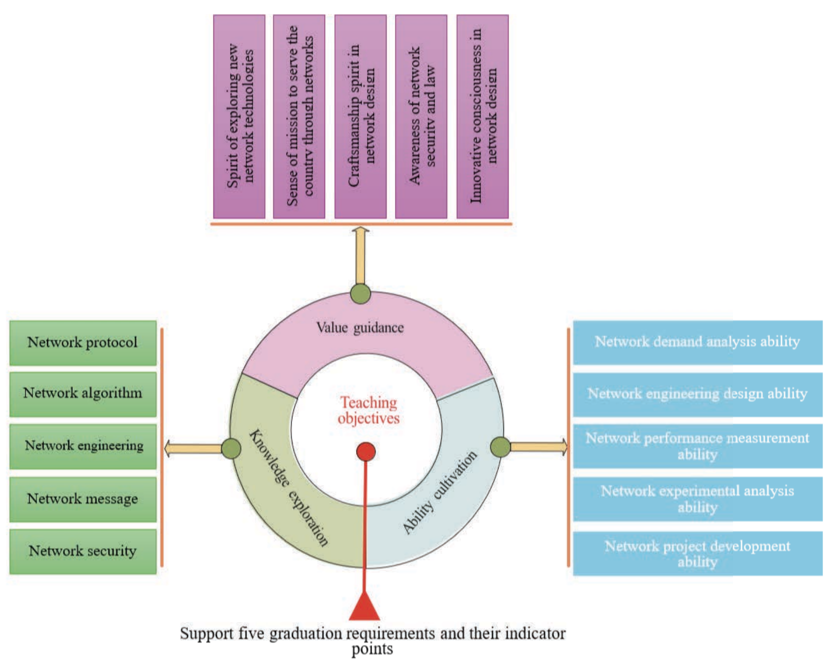
Taking Beijing Institute of Petrochemical Technology as an example, it is positioned as a high-level applied university with the educational philosophy of "advocating practice, emphasizing both knowledge and action." Our computer science and technology program, based on national engineering education professional certification standards and national first-class undergraduate professional standards, aims to cultivate high-quality applied engineering and technical talents for the software and service industries. As a platform course, computer networks are offered to six majors, including computer science and other electrical and information engineering disciplines. Two courses, "Computer Networks A" and "Computer Networks B," are provided. The former is targeted at computer science and technology students, with four credits and 64 hours; the latter has two credits and 32 hours for other majors. As a core course in our national first-class undergraduate computer science and technology program, Computer Networks A is followed by courses such as Computer Network Course Design, Network Communication Programming Technology, and Computer System Security, forming a network curriculum system. Therefore, Computer Networks A has a broader range of course objectives and higher construction requirements.

The analysis of teaching pain points is as follows: (1) There are many layers of network protocols, and the principles are abstract and difficult to understand. In network transmission, the content of protocol packets changes dynamically, and data needs to go through layers of packaging and unpacking processes, making it difficult for students to understand deeply. (2) Network engineering is concealed, and there are few public industry cases. Students have limited practical experience in comprehensive network applications and cannot meet the high-level requirements of network collection, network programming, and security verification in real-world cases. (3) The value guidance is one-sided, and students have a weak sense of mission. Many textbooks and cloud resources mainly introduce classic computer network knowledge or cite foreign original textbooks, with little description of China's network needs and scientific and technological achievements, which is not enough to guide students to pursue the dream of a powerful network country.

Therefore, integrating ideological and political education into the curriculum requires not only revising course objectives but also innovating course construction and teaching methods. When designing the course syllabus, it is necessary to consider extracting ideological and political elements with network characteristics from the teaching objectives to facilitate implementation and evaluation. Although the two computer network courses mentioned above are targeted at different majors, they should be unified in terms of ideological and political education.

2.2. Design of trinity course objectives

Based on the professional certification standards for engineering education, this course needs to support five graduation requirement indicators in the support matrix design for computer science graduation requirements. To this end, five course teaching objectives are correspondingly designed in the course syllabus and decomposed into three aspects: knowledge exploration, skill cultivation, and value guidance (as shown in **Figure 1**).



1- Engineering knowledge	1.5 Have knowledge of network principles and engineering application methods
2- Problem analysis	2.4 Problem analysis and validation through literature research
3- Design/development solutions	3.3 Network system design and implementation with innovation and security
4- Research	4.1 Design of feasible experimental schemes
5- Use of modern tools	5.1 Conduct network project modeling and simulation analysis

Figure 1. Trinity teaching objective design for computer network courses

As can be seen from **Figure 1**, the network knowledge of this course mainly covers network protocols, network algorithms, network engineering, network message analysis, and network security technology. Skill cultivation includes network demand analysis, engineering design, experimental analysis, performance measurement, and project development. The exploration of new network technologies around value guidance, reflecting China's network engineering needs, the safety and independent innovation awareness of network design, and the craftsmanship spirit of network design are the basic ideological and political elements that embody the computer network course.

Achieving these teaching objectives and ideological and political requirements is impossible by relying solely on classroom teaching. It is necessary to expand the design horizon to the entire course construction process and teaching methods, integrating ideological and political elements into every teaching link to achieve the unity of moral and intellectual education.

3. Design of the comprehensive ideological and political model for computer network courses

Comprehensive ideological and political integration in courses refers to the organic incorporation of ideological and political elements into every aspect of course development, aiming to achieve comprehensive cultivation of knowledge, skills, and quality. This integration spans textbook development, classroom teaching, experimental teaching, special topic research, and extracurricular activities. Based on the concept of "unity of knowledge and action," the goal is to cultivate a scientific and rigorous craftsmanship spirit, enhance the sense of mission and safety awareness in serving the country through networks, and foster innovative consciousness and the spirit of exploration in network technology. The design model for the comprehensive ideological and political integration in computer network courses is shown in **Figure 2**.

The evaluation of ideological and political education in courses is integrated into six assessment methods, including in-class tests, online quizzes, experimental scores, special research reports, homework scores, and final exams. This achieves a comprehensive qualitative and quantitative evaluation. In particular, the final exam method requires students to analyze the relationship between China's cutting-edge network technology and the prosperity of the country and the well-being of its people through self-exploration questions on network technology. This enhances their self-confidence and sense of mission and guides students to pay more attention to national network events and have a heartfelt desire to

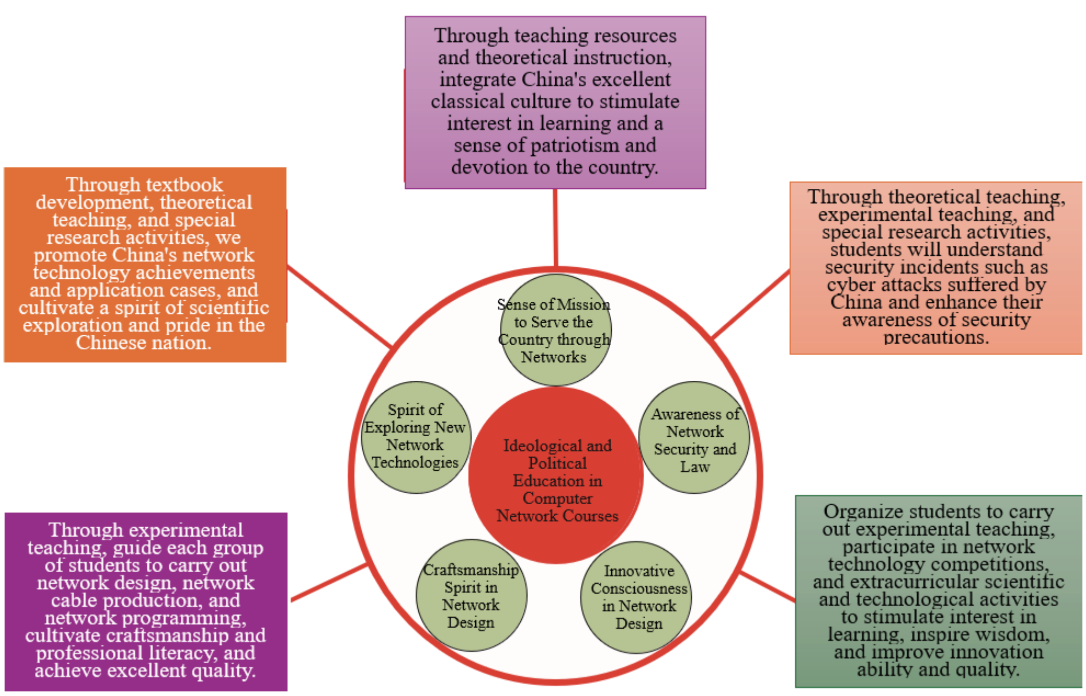


Figure 2. Comprehensive ideological and political design model for computer network courses

serve the country through networks.

4. Implementation model of integrating ideological and political education into teaching links

Guided by five teaching objectives, ideological and political education is integrated into the course through dozens of online teaching themes, and implemented in teaching resource development, theoretical teaching, experimental teaching, special research, and extracurricular activities, facilitating both teaching and evaluation.

4.1. Integrating ideological and political education into teaching content with a focus on a series of network themes

Computer networks possess a typical network architecture and have profoundly influenced various aspects such as society, economy, health, law, and security. When conducting computer network courses, we utilize the principles of TCP/IP protocols and security technologies as the foundation to optimize the design of teaching content. This includes introductions, the physical layer, data link layer, local area networks and wide area networks, network layer, transport layer, application layer, and network security, with the addition of topological content and advanced topics. Excellent entry points for ideological and political education can be found at each level, allowing the integration of concepts like network harmony, inclusivity, service, equality, seeking common ground while reserving differences, and complementary attack and defense into classroom teaching. Emphasis is also placed on incorporating elements of ideological and political education from China.

The knowledge domain and teaching content of computer networks are reconstructed and optimized from the perspectives of protocol algorithm analysis, engineering project practice, and case studies of ideological and political education in the curriculum (as shown in **Figure 3**). By continuously expanding cutting-edge content and applications, such as introducing typical protocols from the industrial field, information hiding techniques, and network programming technologies commonly found in postgraduate entrance examinations for computer science, students' comprehensive application abilities in network design and implementation are cultivated.

From the perspectives of protocol algorithm analysis, engineering project practice, and case studies of ideological and political education in the curriculum, the knowledge domain and teaching content of computer networks are reconstructed and optimized (as shown in **Figure 3**). By continuously expanding cutting-edge content and applications, such as introducing typical protocols in the industrial field, information hiding techniques, and some network programming techniques for the computer science postgraduate entrance examination, students' comprehensive application abilities in network design and implementation are cultivated.

4.2. Integrating teaching resources into ideological and political education through the internet and textbooks

We develop online teaching resources for network courses, utilizing SPOC (Small Private Online Course) and cloud-based classroom resources as the carrier to cultivate students' focus on China's network engineering needs and clarify the responsibilities and commitments of design tasks.

We also compile a series of "1+X" textbooks for computer networks, covering network principles, network programming, protocol applications, and secure development techniques, along with case studies. We promote China's latest scientific and technological achievements in networking, showcase research progress in network security, stimulate students' scientific innovation awareness, and inspire their motivation for network security technology research and development. For example, in the main textbook "Computer Network Tutorial (3rd Edition)," we add content reflecting China's achievements in network communication technology and applications, and expand the comprehensive questions and partial analysis of the graduate entrance examination for computer networks in the past 10 years, providing students with problem-solving ideas for complex network systems.

4.3. Implementing ideological and political education in practical teaching through student group project-driven approach

We adhere to the idea of practical education and carry

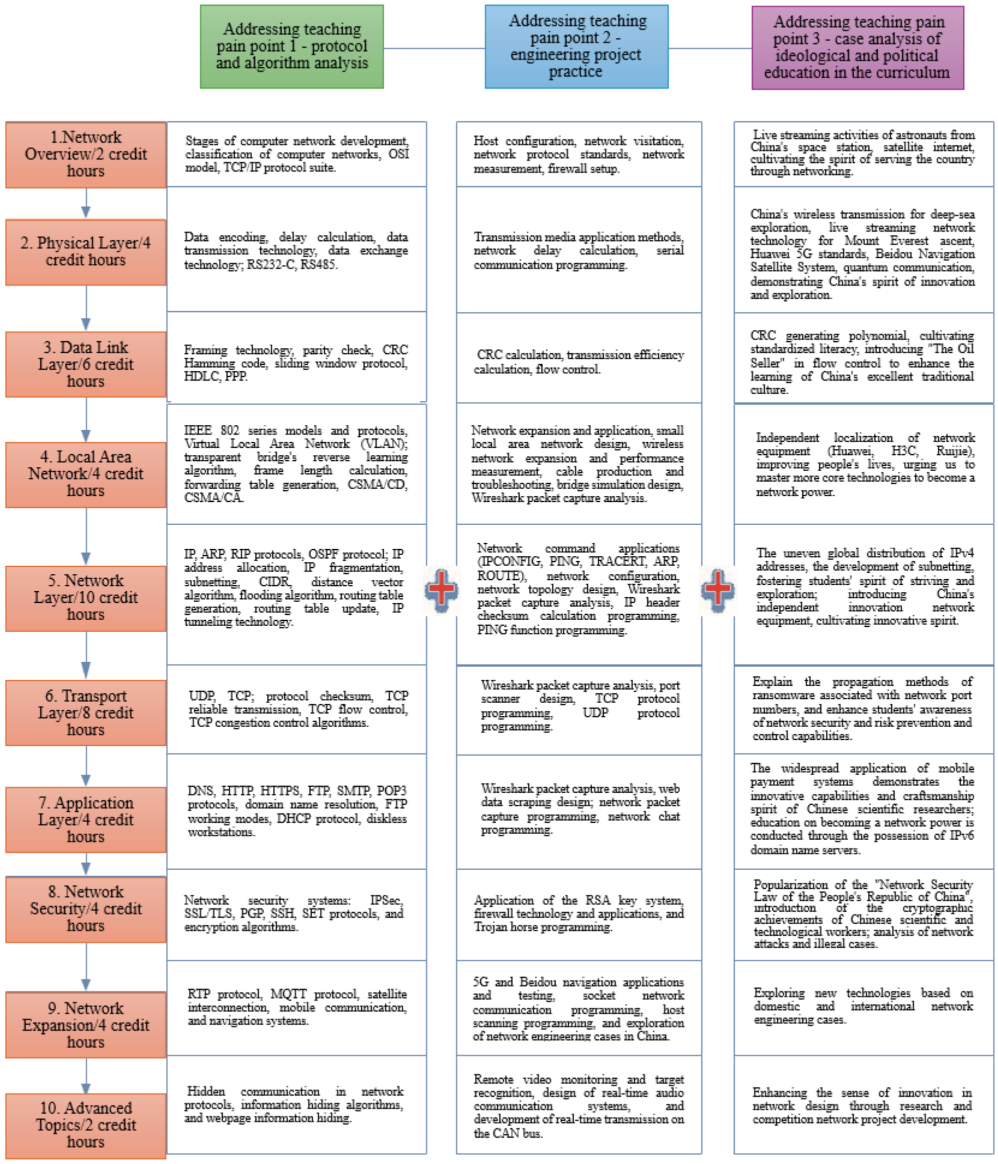


Figure 3. Optimal design of computer network teaching content

out experimental and scientific activities. Through four experimental projects, students' network design capabilities are enhanced while strengthening their sense of mission in network design, cultivating craftsmanship, network security awareness, and innovation consciousness. **Table 1** shows specific design details.

Taking the experiment of small local area network design as an example, the educational concept of the full lifecycle of CDIO (Conceive, Design, Implement, Operate) is adopted [8]. The design tasks include analyzing project requirements, conceiving solutions, designing network topology diagrams, designing laboratory layout diagrams, making network cables, selecting and configuring network equipment, calculating engineering costs, and writing design reports. By explaining design ideas and showcasing the design achievements of previous students, students are guided to develop new ideas and design new solutions in network system layout design. The following two steps are taken to implement the training requirements of the craftsmanship spirit in network design: (1) Each group of two students is guided to make network cables according to standards, and then the quality of the cables is checked and tested individually. Based on the acceptance results, different grades are given for the production, and those who fail are required to redo it. (2) Based on the internet e-commerce platform, each group of students selects and purchases specific network equipment and engineering materials, estimates engineering costs, and optimizes the network design plan.

Table 1. Practical teaching supporting curriculum objective design

Experimental project name	Course objective number	Experimental points	Ideological and political elements of the course	Entry point for ideological and political education
Small Local Area Network Design	3	Network cable production and testing, network topology design, layout design, network engineering equipment selection, and cost estimation.	Craftsmanship spirit in network design; Innovation awareness in network design.	Produce and accept network cables according to standards, select equipment, and estimate project costs; The layout design has a novel theme and practical solutions.
Wireless Network Setup	3	Wireless Router Configuration, Wireless Network Performance Testing and Calculation, Wireless Network Extension, Wireless Network Password Cracking.	Network Security Awareness	RSA Parameter Setting, Password Setting, Wireless Network Cracking Test.
Network Protocol Packet Capture Analysis	4	Focus on network attack and defense strategies, conduct packet capture analysis of major protocols (IP, ICMP, TCP, UDP, FTP, HTTP, etc.), host scanning, port scanning, and packet capture.	Sense of mission to serve the country through networking	Layered analysis of complex systems, selected host attack and defense experiments, and security analysis.
IP Protocol Checksum Calculation Program Design	5	Module Design, Interface Design, Coding and Testing, IP Protocol Packet Capture Verification.	Craftsmanship Spirit in Network Design	Programming according to the structure of the IP protocol and real packet capture verification.

4.4. Implementing flipped classroom teaching integrated with ideological and political education through student group thematic research

Focused on cultivating the spirit of exploring new technologies, thematic research activities and processes are designed [9], including project analysis, network research, report writing, classroom presentations, teacher reviews, report improvement, and grade evaluation. All student groups start with topic selection and project analysis. Based on internet resources, they search for and analyze the latest scientific and technological achievements in networking, incorporating the wisdom and achievements of Chinese people, with themes such as China's satellite internet and Chang'e deep space exploration. After completing the PPT report and Word document, students conduct classroom presentation activities under the organization of teachers to obtain presentation grades. After teacher reviews, students further improve their document materials to obtain report grades. Finally, the grades for these two parts are combined to complete the grade evaluation for the thematic research.

4.5. Developing network project development integrated with ideological and political education through extracurricular activities

Combining industry characteristics, students are organized to design systems such as protocol packet sending and receiving simulation tools, network multi-threaded scanning, industry instrument inspection, equipment anomaly diagnosis, and remote video target detection through extracurricular scientific research projects, academic competition training, and other activities. This develops network application software and expands students' comprehensive design capabilities.

5. Evaluation and effect promotion of computer network courses

Adhering to the comprehensive cultivation of computer network knowledge, abilities, and qualities, and fully integrating ideological and political education into the curriculum has achieved significant results.

5.1. Teaching effectiveness evaluation

Various evaluation methods such as course construction assessment, peer classroom observations, leadership classroom observations, and student evaluations of teaching have been adopted, and the evaluation results have all been excellent, with a student satisfaction rate of 99%. The achievement of course objectives in the past three years is shown in **Figure 4**. It can be seen that the most significant improvement is in Objective 1, which has been elevated from a medium state to a good level.

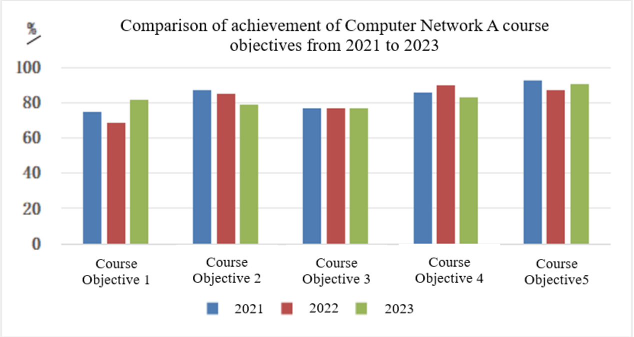


Figure 4. Comparison of achievement of Computer Network A course objectives in the past three years

5.2. Application examples of teaching effectiveness

First, delivering science popularization on network intelligence technology to primary schools for many years. We have partnered with the Daxing District Science and Technology Association in Beijing to participate in the "Rural Revitalization" action plan. This activity has been promoted and reported by multiple mainstream media outlets such as "Learning for a Strong Country." The computer student party branch and the joint student party branch have successively won the second prize of the Red "1+1" activity among Beijing universities in 2021 and 2022.

Second, winning awards for innovative applications of network technology. In the past five years, the participation rate of computer science students in competitions has reached over 90%. We have guided students to win the second prize in the 2023 China College Computer Contest Network Challenge National Finals and the third prize in the 2023 China University Student Computer Design Competition Finals. Many students under our guidance have been honored with the title of Beijing Excellent Undergraduate Graduation Design Thesis for their network technology projects.

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Disclosure statement

The authors declare no conflict of interest.

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Design of Innovative Computer System Experiments Based on General Large Language Models

Jin Zhang[1]*, Xiaoli Gong[1], Xiaopeng Gao[2], Feng Duan[3], Hongqi Xiong[4]

[1]College of Cyber Science, Nankai University, Tianjin 300071, China

[2]School of Computer Science and Engineering, Beihang University, Beijing 100191, China

[3]Tianjin Key Laboratory of Interventional Brain-Computer Interface and Intelligent Rehabilitation, Nankai University, Tianjin 300071, China

[4]School of Physics, Southeast University, Nanjing 211189, China

***Corresponding author:** Jin Zhang, zhangjin@nankai.edu.cn

Abstract:

Disruptive intelligent technologies, such as large language models, are driving the rapid development and formation of new forms of productivity, posing significant challenges to traditional knowledge-driven teaching models and introducing new demands for talent cultivation in higher education. This paper first analyzes the cultivation of students' novel innovative abilities through experimental teaching and proposes a framework for experimental course design characterized by "defined direction, diverse pathways, and flexible goals," as well as a comprehensive experimental design method to develop "intelligent collaborative innovation" capabilities. Then, using the computer organization principles course as an example, it details the design methodology for comprehensive innovation experiment cases. Finally, it evaluates the effectiveness of student ability development based on the implementation of the experimental courses.

Keywords:

Large language model
Experimental design
Computer system
Intelligent collaboration
System capacity

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1. Introduction

Artificial intelligence technology has had a significant impact on higher education. In 2018, the Ministry of Education proposed an action plan to integrate artificial intelligence into the development of the teaching workforce as part of its key work objectives. In the same year, the Ministry issued the "Innovation Action Plan for Artificial Intelligence in Higher Education," which aimed to optimize the scientific and technological innovation system and disciplinary structure in higher education institutions to align with the development of the new generation of artificial intelligence by 2020. The key tasks include promoting the transformation and demonstration of scientific and technological achievements in the field of artificial intelligence in higher education institutions. In 2018, the Ministry of Education decided to pilot the use of artificial intelligence to promote the development of the teaching workforce in Ningxia and Beijing Foreign Studies University, exploring new paths for artificial intelligence to optimize teacher management, reform teacher education, innovate teaching and learning, and support targeted poverty alleviation through education.

Since the emergence of generative intelligence represented by large language models in 2022, the overall productivity of society has been developing at an unprecedented speed with the empowerment of artificial intelligence. Since 2023, the training cost of artificial intelligence has decreased by 40,000 times, and its comprehensive capabilities have increased by 600,000 times. Various auxiliary systems integrating artificial intelligence have increased the work efficiency of knowledge-driven workers by nine times [1]. Similar to transformative technologies such as steam engines and electricity, large language models are profoundly changing the way humans produce and live. The dramatic changes of the times have placed higher demands on talent cultivation in higher education institutions.

The Ministry of Education attaches great importance to the development of new-generation artificial intelligence technologies such as large language models. Minister of Education Jinpeng Huai delivered a keynote speech titled “Working Together to Promote the Application, Sharing, and Innovation of Digital Education” at the World Digital Education Conference 2024, proposing to promote the deep integration of intelligent technology with education and teaching (AI for education), scientific research (AI for science), and society (AI for society). This integration aims to facilitate “intelligent assistance for learning, teaching, management, and research” and uphold the principle of “digital technology for good.” In March 2024, the Ministry of Education launched the “LEAD Action (Artificial Intelligence Large Model Application Demonstration Action)” and promoted the creation of a dedicated large model for the education sector called “GEST” by teachers and students. In this acronym, G stands for Generative, E for Education, S for Special, and T for Transformer. In April 2024, the Ministry of Education announced the first batch of 18 typical cases of “Artificial Intelligence + Higher Education” application scenarios, serving as references for related exploration and practice.

Domestic researchers have conducted studies on the application of artificial intelligence in empowering higher education, ranging from macro-level prospects to specific implementation methods. Wang *et al.* presented a macro-level outlook and analysis based on the opportunities and challenges of artificial intelligence in the digitization of higher education [2]. Wang *et al.* proposed more specific visions and ideas in terms of the basic environment, operational mechanisms, and governance systems [3]. Zhang and Wang explored the potential values and risks that the process of intelligence may bring from the perspective of the relationship between technological change and higher education [4]. Kong *et al.* focused on “new business disciplines” to conduct research on digital and intelligent undergraduate courses [5]. Yao *et al.* attempted to use large language models to transform liberal arts experimental teaching methods [6]. Zhang *et al.* proposed reshaping experimental teaching ability goals in the context of large language models from the perspective of computer system ability training [7]. Zhai *et al.* tried to introduce large language models into teaching evaluation [8]. Xu *et al.* utilized artificial intelligence to construct an innovative practical teaching platform, helping students understand the progress of artificial intelligence technology applications through interdisciplinary integration [9]. Yao *et al.* introduced large language models into liberal arts teaching [6]. Su and Yang analyzed the impact and application of generative intelligence on education [10].

The development of generative intelligence technology and its impact on education are also highly concerning issues for foreign scholars [11,12]. Some scholars have contemplated the potential risks posed by generative intelligence [13], while others are exploring the integration of large language models into experimental teaching [14]. In the United States, six combination methods such as “new interactions” have been proposed for the enabling application of artificial intelligence technology in education and teaching, along with seven action suggestions including “trustworthiness and security” [15]. From the perspectives of teachers and educational technology experts, the UK has provided corresponding initiatives and discussions [16]. Focusing on the application of generative artificial intelligence technology in university teaching, Australia has released core principles and guiding statements covering six aspects: teaching and learning, human and social well-being, transparency, fairness, accountability, and continuous improvement [17].

This article explores the experimental practical ability requirements that students need to possess in the era of large language models, as well as the development ideas for corresponding training goals, based on the current technical characteristics and application methods of large language models.

2. Changes and challenges in capability development demands brought by large language models

2.1. Changes in industrial talent demand brought by artificial intelligence

Artificial intelligence technology has had a disruptive impact on various industries in society, and knowledge-driven work is facing significant shocks and challenges. According to the "Analysis Report on Computer Science and Technology Majors at Beijing University of Aeronautics and Astronautics" [12], there have been drastic changes in recent years in the demand for computer professionals' abilities by enterprises (**Table 1**). The demand for various job positions driven by knowledge

Table 1. Changes in partial skill requirements for computer science jobs (%)

Professional knowledge and skills	Average	2018	2022	Increase
Java language development	28.20	31.10	21.00	-10.10
Database application	34.50	37.40	28.10	-9.30
Web front-end technology	17.70	20.30	12.70	-7.50
Webpage production	15.00	17.60	10.10	-7.50
Java Web development technology	15.10	17.50	10.20	-7.30
Mobile Android application development	11.10	13.40	6.70	-6.70
Java Script development	13.50	15.80	9.20	-6.60
Mobile framework application	11.30	12.50	8.70	-3.80
Big data analysis and processing	10.20	11.10	7.30	-3.80
Distributed systems and cloud computing	10.20	11.00	7.30	-3.50
Statistical analysis	12.50	12.90	10.70	-2.30
Oracle database application	13.00	13.60	11.40	-2.20
Linux system development and application technology	20.70	21.40	19.30	-2.10
Professional scientific research	14.30	15.00	13.00	-2.00
Python language development	12.80	13.00	11.40	-1.60
Data visualization technology	13.80	13.90	12.40	-1.50
Algorithm design and analysis	12.60	13.20	11.70	-1.50
Computer vision application	3.83	3.43	5.01	1.58
C language development	23.88	23.37	27.79	4.42
Computer control technology	5.98	4.47	10.39	5.92
Embedded system development	6.71	5.15	11.48	6.33
Computer hardware development	9.01	6.87	15.32	8.45
Automation and automated line operation and maintenance	16.26	13.45	23.56	10.11

Note: The values represent the proportion of each skill appearing in 100 job descriptions.

and shallow experience has shown a significant decline, while the demand for positions emphasizing innovative abilities such as design has shown a clear upward trend.

Since the industrialization of generative intelligence tools such as large language models in 2023, the training and inference costs of artificial intelligence have dropped dramatically by 75% and 86% per year, respectively. The ARK Foundation predicts that by around 2030, artificial intelligence will automate most knowledge-driven jobs, thereby significantly increasing productivity [1]. Currently, the industry's demand for talent is undergoing drastic changes. Because large language models are essentially probabilistic computers trained on ultra-large-scale data, they can theoretically take over various jobs that can be represented in a data-driven manner through experience.

Driven by artificial intelligence technology, society's demand for industrial talent is undergoing profound changes. At the same time, general higher education institutions face significant challenges in their talent training programs, curriculum systems, and experimental teaching systems, which primarily focus on cultivating knowledge and shallow skills.

2.2. Changes in experimental ability training goals in universities in the era of large language models

Experimental teaching is a critical pathway for cultivating professional practical abilities, bearing the important responsibility of transforming theoretical knowledge into practical abilities. The industry's demand for talent requires individuals to have the ability to solve real and complex problems. Therefore, adjustments to talent training goals in universities must first originate from changes in experimental teaching. In the new era of productivity, experimental ability training goals should align with society's demand for talent abilities.

The emergence of generative intelligence, represented by large language models, has increasingly reduced the importance of knowledge and shallow experience. Consequently, it is necessary to adjust the relevant proportions in experimental teaching. In 2023, the Ministry of Education conducted a phased summary of national experimental teaching demonstration centers, classifying experiments into basic, professional, comprehensive, and innovative categories. Comprehensive and innovative experiments will become the main focus of future designs.

The new generation of artificial intelligence technologies, such as large language models, has redefined society's demand for talent. The important task for experimental teaching in universities is to re-explore and establish training objectives that align with these demands and design more comprehensive and innovative experiments to achieve ability cultivation by abstracting and restoring scenes of real and complex problems.

3. Comprehensive experimental design method for "smart collaborative innovation" ability cultivation

3.1. "Smart collaborative innovation" ability in the era of large language models

Large language models have automated most shallow skill-based work based on experience. Therefore, most work scenarios in various industries in the future will rely on human-machine collaboration to complete tasks, where intelligent agents with responsive capabilities cooperate with humans to accomplish work. Thus, how to better solve real problems with the assistance of artificial intelligence will become a key ability required in the future.

Large language models trained on big data still show inadequate performance in innovative activities in various scenarios. Large language models still struggle to complete innovative work that lacks large-scale data support, i.e., adopting new ideas, mechanisms, methods, or technologies to solve problems with high quality and efficiency. Innovation is not only the core talent ability requirement in the context of new productivity but also the most urgent ability demand for future industries.

Therefore, in the current talent training system, guiding students to learn how to collaborate with intelligent agents such as large language models to achieve innovation together becomes an extremely important ability training goal.

3.2. Design ideas based on the ability training goal of "smart collaborative innovation"

Whether in the process of professional establishment, curriculum construction, or experimental design, it is necessary to combine the ability of "smart collaborative innovation" with the characteristics of the profession and refine it into specific ability goals. In this process, the following five factors should be fully considered.

(1) Era change: Based on clarifying the current mission of higher education, refine and implement the ability training template by combining the development law of higher education with the requirements of the times. For example, the requirement of "integration of education, technology, and talent" should be reflected in the ability design, and the needs of "integration of science and education, and integration of production and education" should be fully considered.

(2) Industry foresight: The output of talent training should ultimately meet the needs of national development and the actual needs of the industry. With the rapid development of productivity, it is necessary to prospectively study the trend of technological development and fully consider the actual development status of the industry when students enter society. For example, it is not appropriate to use outdated software tools or platforms in computer teaching.

(3) Professional characteristics: The refinement of innovation ability should be integrated with subject and professional characteristics. Besides the common methodology, there needs to be a part that combines with the profession, such as debugging and transplantation of computer systems.

(4) Human-machine differences: It is necessary to fully understand the "incapabilities" of intelligent agents such as large language models, especially those determined by mechanisms. This is the most urgent demand for talent in society in the future. For example, the ability to design computer systems for a specific vertical application or brand-new demand.

(5) Scientific and technological ethics: Scientific and technological ethics are the values and behavioral norms that need to be followed in carrying out scientific research, technology development, and other scientific and technological activities. It is an important guarantee for promoting the healthy development of scientific and technological undertakings [18]. Technology for the better is a principle that needs to be adhered to and is an essential quality for students in the era of artificial intelligence.

3.3. Comprehensive innovative experimental design framework for real problems

To cultivate abilities required in the era of large language models, such as smart collaborative innovation, experimental teaching is bound to transform towards comprehensive innovative experiments facing real problems. From the perspective of the experimental process and results, teaching experiments can be roughly divided into four types as shown in **Table 2**.

To cultivate students' innovative abilities and restore the complex scenarios of real-world problems, propositional semi-open experiments and open experiments are preferred choices for conducting comprehensive and innovative experiments. This paper proposes a comprehensive innovative experimental

Table 2. Classification of teaching experiments

Experiment type	Experiment process (technical route)	Experiment results	Application scenario description
Deterministic experiment	Determinate	Determinate	Used to reproduce or verify existing conclusions
Propositional semi-open experiment	Uncertain	Determinate	Used to examine and train students' design and practical abilities
Practical semi-open experiment	Determinate	Uncertain	Suitable for examining and training students' practical operation skills
Open experiment	Uncertain	Uncertain	Suitable for students' innovative training projects

design framework of "established direction, multiple paths, and dynamic results," as shown in **Figure 1**. The left side of the figure represents the teacher's progressive research, judgment, and selection of design work, while the right side represents the supporting work carried out on intelligent agents such as large language models for verification.

Within the context of real-world problems, this framework sets a clear but flexible goal, encouraging students to explore solutions from different perspectives using diversified methods and approaches. This design not only tests students' innovative thinking but also strengthens their adaptability in the face of uncertainty and challenges. The dynamic result evaluation mechanism ensures the comprehensiveness and fairness of the experimental process, promoting further deep thinking and continuous improvement among students.

Before carrying out comprehensive experimental design, it is first necessary to clarify which abilities are planned to be trained and cultivated in this experiment. In principle, these abilities should be designed and specified in the professional or course plan.

(1) Selection of real problems: Experiments should originate from real industrial problems, scientific research problems, or engineering practice problems, and the design of experimental activities should be based on the solution of the core or key parts of these problems. The problems should have a certain timeliness, stimulating students' interest while cultivating their attention to the forefront of the industry. This is also an effective way to integrate ideological and political elements into the curriculum. In problem selection, on the one hand, it is necessary to ensure that the solution of the problem requires the integrated use of

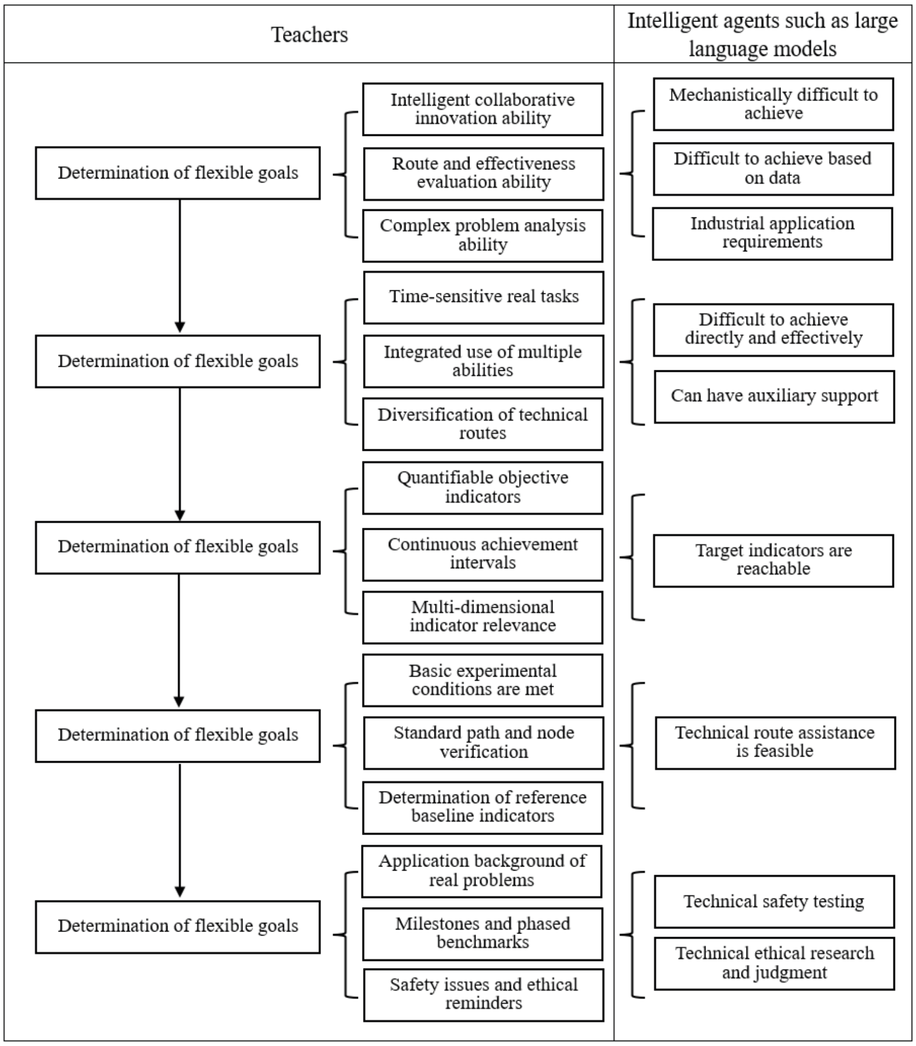


Figure 1. Experimental design framework

multiple abilities and knowledge from multiple fields; on the other hand, it is also necessary to ensure that multiple different technical routes can be adopted to complete related work, so as to train students' ability to analyze and solve problems. The designed experimental propositions should be tasks that are difficult for intelligent agents such as large language models to complete directly but can be assisted and accelerated through various auxiliary tasks.

(2) Determination of flexible goals: "Flexibility" refers to the fact that the final result goal is not a standard value but a reasonable range, which stimulates students' innovative spirit and challenge awareness, prompts them to continuously think and adjust their own solutions in pursuit of better results, and even set new records. The final indicators can be functional or technical, but they should all have quantifiable characteristics and continuous distribution features, that is, they should have comparable characteristics. If there are multiple dimensions of indicators, the correlation characteristics between the indicator dimensions, such as whether there is orthogonality, should be fully considered. At the same time, intelligent agents such as large language models can cooperate to complete the optimization of relevant indicators.

(3) Technical route verification: First, confirm that the basic environment can support the completion of the experiment, that is, relevant sites, equipment, consumables, and other conditions are available; secondly, design the standard path for experiment completion, fully consider the various technical routes that may exist in the experiment, and provide intermediate milestone nodes; at the same time, provide milestone node phased output delivery results to prevent accidents from causing the experiment to be unable to continue; finally, carry out verification experiments with the cooperation of intelligent agents such as large language models, and provide reference indicators for each node and the overall experiment.

(4) Writing of the experiment guide: Firstly, focus on the elaboration and explanation of the experimental scheme design background, strengthen the actual needs of engineering, industry, society, and other aspects, and help students develop the habit of caring about politics, industrial development, cutting-edge technology, and national economy and people's livelihood; secondly, while giving suggested routes, appropriately explain the division of each link of the task, especially the role and suggested indicators of milestone nodes; finally, fully study and judge the technical safety issues and ethical issues that may arise in the experiment, and explain them in the guide after verification through intelligent agents such as large language models.

4. Design and operation examples of comprehensive innovative experiments

4.1. Introduction to the course implementation

The Principles of Computer Organization is a landmark course in computer system courses. It is also one of the 12 core courses for computer science majors under the "101 Plan" of the Ministry of Education, occupying a pivotal position in the training system for computer professionals. It is included in the comprehensive examination outline for computer science majors in the national postgraduate entrance examination along with courses such as data structure, operating systems, and computer networks.

Nankai University offers a comprehensive innovative experiment course in Principles of Computer Organization for second-year undergraduates. This course is among the first batch of national first-class undergraduate courses (offline), a politically and morally oriented course demonstration in Tianjin universities, an innovation and entrepreneurship demonstration course in Tianjin, and a selected course for the Ministry of Education—Huawei Smart Base Project. The iterative construction cycle of this course is relatively long, and the construction foundation is sound. With "ability training" as the goal and "iterative design" as the guide, the course cultivates students' innovation ability, independent learning ability, and ability to solve real and complex problems through the study of computer

Table 3. Detailed table of abilities in computer system direction

Learning ability level	Computer system ability	Description
Analysis	Migration	Compare and analyze different systems to migrate existing tasks to other platforms
	Decomposition	Analyze the decomposition of existing systems or work into multiple subsystems
	Error correction	Analyze based on signs, feedback, and other information to find, locate, and correct errors
	Abstraction	Analyze complex systems and describe them in hierarchical and categorical ways
Evaluation	Assessment	Conduct quantitative evaluations of a system or task from multiple perspectives
	Selection	Choose from multiple routes or systems based on certain principles
	Reconstruction	Implement the original system using different methods or approaches
Innovation	Integration	Connect multiple systems to ensure smooth operation
	Optimization	Enhance the efficiency of existing systems by modifying them according to specific goals
	Design	Create new systems based on target requirements

system evaluation, instruction design, data path design, pipeline design, and storage system design. It has the implementation conditions for "intelligent collaboration" comprehensive innovative experiments.

4.2. Experiment design and approach

4.2.1. Design of ability training objectives

Computer system ability refers to the ability to apply the basic principles of computer systems to build application systems with computer technology as the core, and then solve practical problems. This is not only the design and expression in the International Computer Science Curriculum Guidelines (CS2013) but also the ability training direction strongly supported by the Computer Teaching Guidance Committee of the Ministry of Education. Combining educational psychologist Benjamin Bloom's six-level cognitive hierarchy thinking model (memory, understanding, application, analysis, evaluation, and innovation), in the Principles of Computer Organization course, "intelligent collaborative innovation ability" is defined as three levels of ability: analysis, evaluation, and innovation, which are broken down into 10 abilities as shown in **Table 3** [12].

4.2.2. Experimental topic design

Based on the principles and ideas of "established direction, multiple paths, and dynamic results," the core computational task of conventional large language models, namely the implementation and optimization of the "attention score" calculation task, was selected as the topic for this experiment. This topic bears significant characteristics of the times, aligns with the requirements of the "Four Orientations," and is likely to spark students' interest. To ensure a gradual progression, the overall task is divided into two parts: "implementation" and "optimization." The core objective of the "implementation" section is to cultivate students' abilities in "abstraction" and "decomposition," which involves quickly abstracting key technical aspects and core tasks from real-world problems. In this instance, the core task is identified as implementing tensor multiplication. The "optimization" section, on the other hand, is designed to exercise other abilities. Students can choose different hardware platforms and programming languages to construct various technical routes and select different optimization methods to ultimately achieve the optimization goals. This approach facilitates personalized teaching centered around learning and the student.

4.2.3. Flexible goal design

In line with the original design intent, the flexible goal for this experiment is set as the "time metric," specifically, the shortest execution time for the optimized program. The experimental guidelines emphasize the design requirement of "everything for time." Different routes, platforms, and methods yield varied results. This semi-open experimental approach, spanning platforms, languages, methods, and even curricular knowledge systems, greatly promotes students' autonomous learning abilities and their capacity to solve real and complex problems.

Similarly, space metrics can be chosen as optimization goals, such as spatio-temporal optimization in combination with FPGA design. Especially with appropriate hardware support, power consumption can also be considered an optimization target, and even cost factors can be incorporated into the optimization objectives.

4.2.4. Technical route design

To comprehensively cultivate the 10 target abilities, the experiment is divided into three parts: code generation (i.e., implementation), performance optimization, and task migration.

(1) Code generation: Students need to abstract the matrix multiplication task, particularly the specific tensor dimensions, based on the problem background provided in the experimental guidelines. This section focuses on developing students' abstraction skills. Here, large language models can be used to understand the problem's background knowledge and determine various parameters. Students must explain the reasons for abstraction, their thinking process, and the determination of quantitative parameters in a report document (**Figure 2**).

Based on the control experiment's standard requirements (i.e., various parameter configurations), students can write code manually or with the assistance of large language models. This code needs to be jointly evaluated by humans and large language models, focusing primarily on code standardization and interface checks. Additionally, students have the freedom to choose their programming language and hardware platform. The experiment provides x86, MIPS, and ARM hardware platforms, with ARM being the final target platform for migration.

(2) Performance optimization: In this experiment, time optimization is taken as an example to set optimization requirements. Students are required to design their own routes and methods for implementation, which can be based on optimizing the methods provided

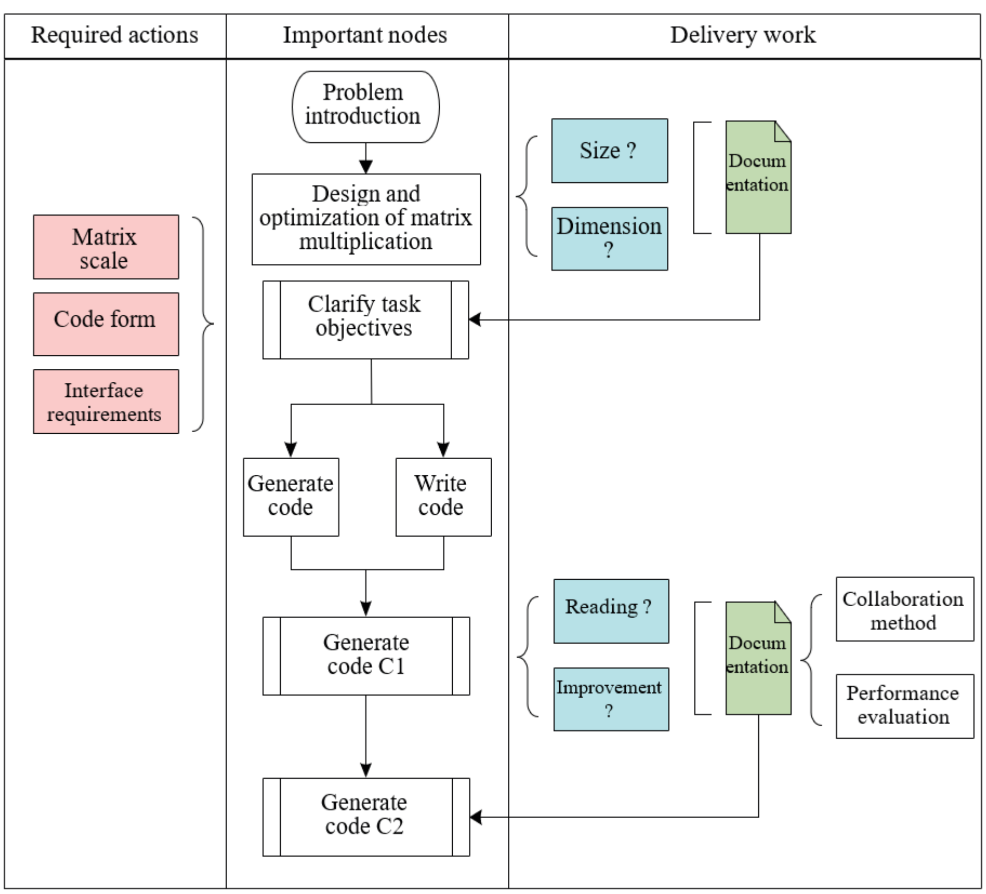


Figure 2. Schematic diagram of the technical route for code generation experiment. Note: The red part represents the content that will be given in the experiment guide; the blue part represents the work that can be done in collaboration with the large language model; and the green part represents the work documents that need to be delivered.

Figure 3. Schematic diagram of the technical route for performance optimization experiment. Note: The red part represents the content that will be given in the experiment guide; the blue part represents the work that can be done in collaboration with the large language model; and the green part represents the work documents that need to be delivered.

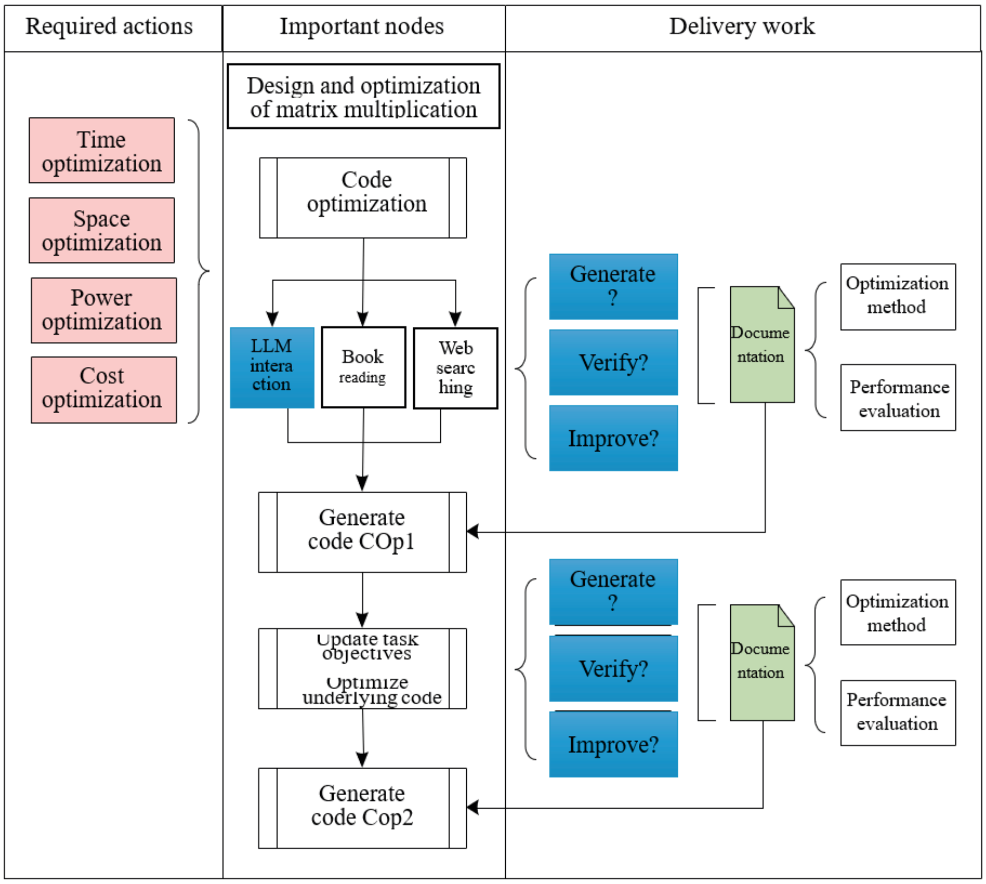
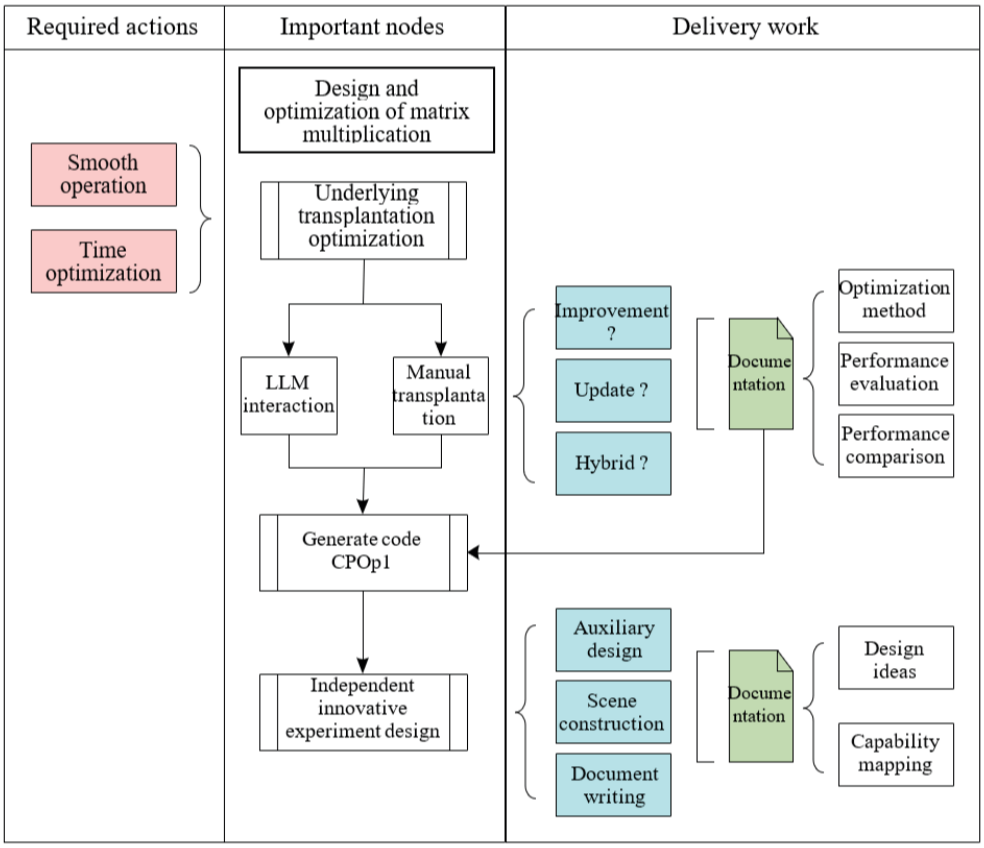


Figure 4. Schematic diagram of the technical route for task migration experiment. Note: The red part represents the content that will be given in the experiment guide; the blue part represents the work that can be done in collaboration with the large language model; and the green part represents the work documents that need to be delivered.



in the textbook, searching for relevant solutions through the internet or large language models, or even directly having the large language model assist in modifying the code to improve performance. However, before that, students need to collaborate with the large model to build a basic performance evaluation model and method, so as to evaluate the effectiveness of future improvements. At the same time, after completing the optimization at the high-level language level, students still need to optimize the code at the lower level such as assembly language, evaluate the corresponding results, and write relevant reports (**Figure 3**).

(3) Task migration: Students need to complete a transplantation task from the underlying code to the ARM platform, and collaborate with the large language model again after the transplantation to ensure that the transplanted code can operate smoothly and achieve optimal performance.

After the in-class experiment is completed, students are required to complete an independent and innovative experiment design based on this experiment to improve their own weaknesses. In the process of designing the experiment, they can use the large language model for assistance and collaboration to complete tasks such as scene construction and experiment guide writing (**Figure 4**).

4.2.5. Experiment guide design

This experiment does not involve technical safety-related content. Instead, it provides hints on the experimental environment, experimental conditions, experiment submission, and key node selection in the technical route.

In terms of the experimental environment, the guide introduces the use of virtual machine systems to support different hardware platforms and provides instructions on usage methods and permissions. Regarding experimental conditions, this experiment does not limit the use of large language model tools. The guide encourages students to select multiple large models for comparison or to work together in combination, aiming to cultivate and enhance their evaluation and selection abilities. As for experiment submission, the guide sets the format and location for submission.

4.2.6. Ability training design

In this comprehensive experiment, there are corresponding experimental sections and task designs for each of the 10 abilities derived from "intelligent collaborative innovation ability," as detailed in **Table 4**.

5. Experiment implementation and effectiveness analysis

5.1. Experiment organization and operation

The experiment was conducted during the second semester of the 2023–2024 academic year in the "Computer Organization Principles" course at Nankai

Table 4. Correspondence table for experimental section design and abilities

Learning ability level	Computer system ability	Corresponding experimental section and design	Corresponding tasks
Analysis	Migration	Moving existing work to platforms like ARM	Task migration
	Decomposition	Exporting problems as tensor multiplication	Code generation
	Error correction	Experimental debugging	Various tasks
	Abstraction	Exporting problems as tensor multiplication	Code generation
Evaluation	Assessment	Establishing performance evaluation methods	Performance optimization
	Selection	Choosing optimization schemes based on large language model suggestions	Various tasks
	Reconstruction	Optimization for the target transplantation platform	Task migration
Innovation	Integration	Submitting interfaces and integrating code	Various tasks
	Optimization	Performance optimization, task migration	Various tasks
	Design	Independent and innovative experimental design	Task migration

University. The participants were all undergraduate students majoring in computer science and technology from the 2022 grade, totaling 141 students.

The experiment was divided into two parts: an independent 3-hour class experiment requiring students to complete code generation and performance optimization individually, and group work on task migration after class.

The experiment was conducted at the Computer Experimental Teaching Center of Nankai University, with experimental conditions including various open large models that can be directly accessed, as well as x86, MIPS, and ARM platforms. The MIPS platform was provided in the form of a virtual machine, while the ARM platform was supplied through a remote connection to a physical server.

5.2. Experimental data analysis

All 141 students participating in the experiment submitted experimental reports, and 135 of them completed the entire experimental process, with an overall completion rate of 95.7%. This indicates that the overall design of the experiment aligns with the students' ability requirements. During the experiment, most students chose "Tongyi Qianwen" and "Wenxin Yiyan" as their large language models, while three other large language models were also selected. This demonstrates the openness of the experiment and confirms that there are no significant differences among various large language models in assisting system optimization.

In terms of experimental platform selection, students mainly used computer platforms based on x86 and ARM architectures. Most students conducted experiments primarily using the C/C++ programming language, indicating that C/C++ is still excellent in terms of implementation efficiency and has gained students' recognition. At the same time, given Python's advantages in data processing and rapid development, some students chose to use Python.

The final experimental results were submitted in groups, and the specific distribution is shown in **Figure 5**. The figure shows that with the assistance of large models, 95.7% of the groups were able to successfully complete the migration and improvement of experimental tasks. Among them, nearly 75% of the groups could complete the algorithm within 25 seconds, and about 17% of the groups could further optimize the program to reduce the execution time to less than 10 seconds. The results basically show a bimodal distribution, which aligns with the original intention of the experimental design and achieves effective graded evaluation.

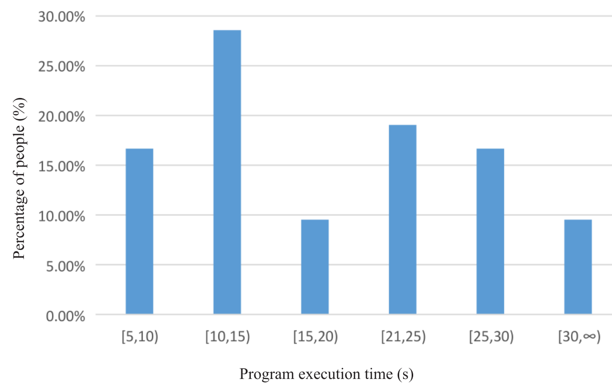


Figure 5. Distribution of experimental performance optimization time

5.3. Analysis of experimental results

Through analyzing the experimental reports, it was found that students encountered various programming challenges and performance bottlenecks during the process of writing and optimizing matrix multiplication code. With the assistance of large language models, they learned to address these issues in practice, which not only deepened their understanding of basic computer science knowledge but also provided them with a more profound comprehension and experience of "intelligent collaboration." By collaborating with intelligent systems, students felt the power of smart technology in learning and work, and gained a deeper insight into the application of large models in future technology.

Beyond meeting the basic experimental requirements, students achieved the fundamental teaching objectives of the course and demonstrated enthusiasm for knowledge exploration and a deep understanding of technical applications. Through independent and innovative experimental design, they further solidified their comprehension of intelligent collaboration capabilities. Based on the students' experimental performance, their independent innovations mainly fell into two categories:

The first category involved innovations in the experimental background. Referring to the experimental guidebook, students transferred the experimental context to different domains. For instance, some students selected architectural mechanisms such as cache and pipelines, and explored their performance and optimization strategies in various application scenarios using large models. Others focused on algorithmic levels, such as classic algorithms like Gaussian elimination and Fourier transform, experimenting to verify their efficiency and applicability, and even attempting to improve or optimize these algorithms.

The second category encompassed innovations in the experimental steps. Some students were not satisfied with the existing experimental framework and proposed additional steps to facilitate deeper learning and understanding. For example, students migrated the experiment to an FPGA (Field Programmable Gate Array), which required not only a profound knowledge of hardware programming but also mastery of implementing and optimizing algorithms at the hardware level.

China Education News reported on this work online [19]. Additionally, during the interview session after the experiment, all students mentioned the issue of learning pathways, specifically the shift from "learning from textbooks to learning from intelligence," which represents a significant direction in teaching reform: cultivating self-learning abilities in the era of large language models.

6. Conclusion

Artificial intelligence technologies, such as large language models, are disruptive and revolutionary, as mentioned in the discussion of new productive forces. They are triggering transformations in various industries and significantly impacting talent demand. In light of this, higher education reform must explore the application of AI technologies in various aspects, including assisting students, teachers, administrators, and researchers, while also emphasizing the cultivation of new talent abilities. This paper proposes the ability training goal of "intelligent collaborative innovation" and designs a comprehensive experimental teaching method based on it, applying it to practical teaching.

In the era of new productive forces, teaching reform research in higher education must be forward-looking, focusing on future industry trends, real business scenarios, and changes in ability requirements. Besides the emphasis on innovative ability training discussed in this paper, cultivating self-learning abilities is also a crucial task that aligns with the development needs of new productive forces and will become an important research direction in future experimental education and teaching reform.

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Disclosure statement

The authors declare no conflict of interest.

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Research on Secure Data Transmission and Storage Based on Blockchain Technology

Shicheng Xiao*
Henan Branch of China Telecom Corporation Limited, Zhengzhou 450000, Henan Province, China

Corresponding author: Shicheng Xiao, 284872799@qq.com

Abstract:

With the ongoing advancement of information technology, there has been a growing focus on the security issue of information transmission and storage. Ensuring the secure transmission and efficient storage of data in the digital age has emerged as a critical issue. This article explores innovative solutions based on blockchain technology, aiming to enhance the security and reliability of data management systems. Such systems can accelerate work efficiency across various sectors, safeguard the security of data applications, ensure the rationality of advanced data utilization, and offer fresh insights for the sustainable development and construction of our digital society.

Keywords:

Blockchain technology
Data transmission; Data storage
Hash function

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1. Introduction

At present, with the increase in social business activities, the scale of data is also constantly expanding. The transmission and application of various data information are extensive and comprehensive, aiming to ensure the security and reliability of data application in this evolving background. In this development context, blockchain technology, as a decentralized distributed ledger system, has garnered increasing attention and is tamper-resistant. Currently, blockchain technology serves as an innovative approach to mitigating security risks in data transmission and storage, enhancing stability, and preventing data loss and issues [1]. This paper emphasizes secure data transmission and accurate processing using blockchain technology. By combining the analysis of the basic characteristics of blockchain technology, we hope to build a verifiable and truly decentralized data management system.

2. Application of blockchain in data transmission

Presently, the volume of data in our country is continually increasing, possessing immense value and providing significant assistance to various aspects of production and life [2]. In this regard, it is necessary to combine the basic characteristics of blockchain technology and understand the main trend of data growth in China; on this basis, the use of blockchain technology to store data reasonably can ensure the security of data storage and data transmission process, ensuring data integrity is crucial to prevent irreversible losses and problems, as it safeguards against data loss risks [3].

2.1. Integrity verification of data transmission

Data must be utilized sensibly and efficiently, necessitating precise transmission. During data transmission, blockchain technology's distributed and immutable traits become particularly evident [4]. Hence, blockchain technology, when applied to data transmission, offers a more robust and comprehensive data integrity verification mechanism, whose significance cannot be overlooked. In the process of the application of blockchain technology, each data transaction will be fully recorded on the distributed ledger in the form of blocks, without any omissions. During data transmission, nodes can contain multiple hash values [5], and each block links to the previous one through its hash value, forming a complete data chain. In the process of data transmission, nodes involved in data transmission can also form accurate verification with the help of consensus algorithms, and can fully guarantee the consistency of data, which is conducive to the efficient application of data. It is important to note that any attempt to tamper with the data may be detected by these systems in a timely manner, and the system can respond immediately to deal with and detect the behavior of data tampering, so as to avoid irreparable serious impact. Therefore, blockchain technology serves as a third-party trust institution in data transmission, ensuring data integrity and comprehensiveness, and effectively preventing potential damage or tampering. This process ensures the safe transmission of information and data, making data transmission and storage more reliable and reducing unnecessary risks as much as possible [6].

2.2. Decentralized control

Promoting data transmission with blockchain technology showcases its unique decentralized control, forming a perfect mechanism that maximizes its positive role and comprehensive value. Eliminating centralized authority allows for comprehensive management of the distributed network. Traditional data transmission relies on other technical means in the process of promotion, however, it fails to ensure security and rationality during the transmission [7], potentially leading to increased issues of omission and data loss. Within this system, the central server or authority verifies and strictly controls the information flow, yet this results in an increasing number of organizations and third parties being exposed to data, thereby hindering strict security management and comprehensive utilization of the information. However, blockchain technology is different from these traditional technologies mentioned above, the blockchain is distributed in the network nodes, which participate in the verification and accurate recording of this data information, so as to eliminate the single point of control that exists in traditional systems. This fundamental feature of decentralization holds immense significance and value for data transmission, as it embodies the fairness and transparency of the process, which can minimize the risk of a single point of failure, and reduce the over-reliance on centralized entities. By effectively utilizing the node consensus mechanism, the security of data applications during transmission is fully ensured, enhancing the consistency of data transmission. This minimizes the risk of any omissions or losses. All staff involved in the data transmission process can gain greater trust, enabling a more seamless realization of data transmission objectives. A more open and democratic model of governance.

3. Effective application of blockchain technology in data storage

Combined with the above, it is evident that blockchain technology, apart from its comprehensive application in data transmission, also plays a significant and non-negligible role in data storage. The use of blockchain technology to store data can ensure the security and effectiveness of the data, can fully play the value and role of relevant technologies, and avoid irreversible risks in the process of storing data and data loss problems, affecting the value of these data and reasonable applications [8].

3.1. Distributed storage

In the field of storing a large amount of data information, the application of blockchain technology cannot be ignored. Blockchain technology, with its distributed storage mechanism, offers new opportunities for the storage and management of data information, providing a revolutionary solution to the problem. This represents a major innovation in the field of information data storage. In the process of data information storage, the traditional centralized storage system is commonly used, thus posing risks of data loss and issues related to a single point of failure. When these problems arise, the impact is severe, dealing a significant blow to the value of the data itself. Blockchain technology enables a novel approach to distributed data storage, distinct from traditional methods. This advanced technology facilitates decentralized storage by distributing data across numerous nodes, ensuring enhanced security and transparency. In the network, each node saves complete data copies, and the application effect is ideal. It should also be noted that the distributed storage method, with the help of smart contracts and decentralized protocols, can ensure the integrity and security of data applications, as well as the data involved. Distributed storage systems like HBase and Hive implement robust data recovery strategies. For instance, in a distributed storage environment with 16 physical servers, each hosting multiple virtual machines [9], the integrity of HBase and Hive databases can be maintained by backing up physical servers, analyzing block file structures, and carefully piecing together and validating block files before importing them back into the databases. Effective implementation of this distributed storage method can significantly enhance the application efficiency of these data, while their robustness and anti-attack performance also experience rapid development and progress. This results in enhanced accessibility and more prominent availability of the data. Therefore, we must pay attention to the improvement of the distributed storage of these data, and change the backward storage technology means through the relevant technologies and methods of distributed storage, reflecting the efficient development of data technology storage and application.

3.2. Security and scalability

Blockchain technology, unlike previous technologies, offers a multitude of advantages and values. Among these, security and scalability stand out as particularly significant. For instance, its decentralized nature ensures that transaction records are immutable and transparent, enhancing security. Additionally, blockchain's architecture allows for increased scalability by adding more network nodes, enabling it to handle large volumes of transactions more efficiently. In data storage, a well-designed blockchain application system can further emphasize its security and scalability, playing a crucial role. Blockchain leverages cryptographic techniques, hash functions, and asymmetric encryption algorithms to ensure the confidentiality and integrity of data, as evidenced by its application in financial industries and other sectors, but also makes these data more complete [10]. Smart contracts and distributed consensus mechanisms, once effectively implemented, can further bolster the consensus mechanism applied to these data, playing a crucial verification role and yielding positive outcomes. During the actual application of these data, the promotion of these technologies, coupled with various preventive measures, can effectively thwart malicious tampering and mitigate undesirable outcomes or unauthorized access as far as possible. This form obviously forms a comprehensive protection for this data information, which can effectively improve the application security of data information. After many practices, the application of blockchain technology has formed a perfect security framework, which can make the data in the process of storage and transmission comprehensive and provide more adequate and reliable protection [11].

At the same time, we must recognize that blockchain scalability hinges on optimizing the distributed node network. During data storage and distribution in blockchain technology, distributed ledger technology will be incorporated. There are multiple nodes in the network, and data is stored in these different nodes. Overall, a decentralized storage structure is formed. The implementation of this storage structure can continuously share the burden of data storage and processing, and can also rapidly improve the scalability of the system, and dynamically increase various nodes required in combination with the development and change of relevant needs. It can realize the flexible adjustment and optimal configuration of the existing system information resources. The purpose of data storage through such measures is to effectively cope with the growing amount of data information and the expanding and evolving scale of data information, while meeting storage requirements without compromising security or performance. While ensuring data transmission security and data storage performance, it can also store a large number of multi-faceted and diversified data information content [12].

4. Application of blockchain technology

In the above systematic description of the data transmission and data information storage process, the advantages and value of blockchain technology become evident, enabling the reasonable application of data information and tapping into its application value and underlying potential. In the subsequent analysis, we will delve into the application of blockchain technology and its foundational principles, aiming to enhance our understanding and facilitate more effective execution of various tasks in the reasonable application of these blockchain technologies [13,14].

4.1. Integration method of blockchain

The main blockchain network constitutes the core content of the blockchain technology system, responsible for managing the overall distributed ledger and effectively maintaining the consensus mechanism. Its purpose is to enhance efforts in this field, ensuring system application security while fully showcasing decentralized characteristics. The backbone of the system is the main chain, which carries the infrastructure development and construction of the overall blockchain.

In addition to the network of the main blockchain mentioned above, there is a dedicated side chain, the role of the side chain is to accurately handle the security risks in the process of secure data transmission and data storage, with special work responsibilities, and the strategy is an independent blockchain connected with the main chain. Therefore, it also has relatively independent rules and covers smart contracts, which can provide flexibility and efficient preparation for the effective implementation of specific tasks, thereby enhancing the flexibility of the work [15].

The customized data transmission function can be perfected in the policy, including the transmission, accurate verification of data, and the establishment of a basic confirmation mechanism. The purpose is to ensure the integrity of these data in the process of transmission, reflecting the reliability of these data. Undoubtedly, the effective implementation of this mechanism can also make the application of various data information in the network more secure and ensure that the flow process can be more stable.

The smart contract deployed on the side chain covers the logic of data processing and transmission, is responsible for the validity and invisible verification of the data, manages the basic rights of each participant, and records key data information when needed. The design of this smart contract results in automatic operation and safe execution in the system.

The implementation of the side chain serves as a storage function, encompassing both the secure storage of these data and the efficient storage of vast amounts of diverse data. By leveraging smart contract data, the distribution of storage across different nodes of the side chain helps ensure data confidentiality and integrity and facilitates a more efficient system, thus providing more stable and reliable data storage solutions.

The main chain and side chain can achieve the goal of interactive development with the help of smart contracts, which are conducive to ensuring the safe transmission and stable storage of data. The verification of key source data and data information is transmitted to the main chain with the help of smart contracts, in the hope that the consistent needs of the system can be maintained. This interaction mechanism can realize the synergistic development of the main chain and the side chain, and ensure the safety and stability of the development and progress of the system.

4.2. Technical details of data transmission and storage

The choice of the hash function is crucial. During data transmission and storage, there is a tendency to utilize hash functions with enhanced security to guarantee efficient data processing in these processes. By applying the corresponding hash function selected, the data block can be hashed, and a fixed-length hash value can be generated. The original data uniquely identified by this hash value can be verified for data integrity, and the data identification can be completed.

5. Conclusion

This paper mainly focused on the role and value of blockchain technology in the safe transmission and storage of data. By applying blockchain technology, a robust and comprehensive data management system can be more effectively established, while the utilization of hash functions and digital signatures with enhanced security further guarantees the secure transmission and storage of data. A substantial and more efficient digital data management system can be built in future development.

Disclosure statement

The author declares no conflict of interest.

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