

PAPER

Online Engineering Education and Regional Growth: Innovation, Digitalization, and Policy

Cai Wei , Sufian
Jusoh, Radin Siti Aishah
Radin A Rahman ,
Wang Si Ya

UKM, Kuala Lumpur, Malaysia

[P118896@siswa.
ukm.edu.my](mailto:P118896@siswa.ukm.edu.my)

ABSTRACT

Building upon traditional research on engineering education, innovation, and economic growth, this study introduces additional control variables such as air quality and talent concentration and extends the analytical scope to include underdeveloped regions in western China, thus advancing beyond conventional research paradigms. The research investigates the impact of high-quality engineering education on regional economic sustainability across nine diverse Chinese regions from 2014 to 2024. Grounded in regional innovation systems theory, the study examines both the direct effects of educational investment on economic outcomes and indirect effects mediated through innovation, digital transformation, and industrial upgrading. Findings indicate that financial investment in engineering education significantly promotes regional economic growth, although effects differ notably across regions. Developed areas in China experience economic growth primarily driven by innovation, whereas regions such as Henan and Heilongjiang rely more on industrial modernization. Additional control variables, including R&D personnel density and air quality, further influence these relationships. The study emphasized the importance of zoning to promote optimization of school investment.

KEYWORDS

engineering education, technological innovation in engineering, engineering education and economic development, R&D staff density and air quality, regional innovation systems theory

1 INTRODUCTION

China has started its transition to an innovation-based economy through the development of online engineering education and digital innovation systems. The research demonstrates how superior online engineering education platforms together with virtual collaboration technologies drive regional economic expansion and innovation potential. The research uses a regional innovation systems framework to study nine different Chinese regions from 2014 to 2024. The study

Wei, C., Jusoh, S., Rahman, R. S. A. R. A., Ya, W. S. (2025). Online Engineering Education and Regional Growth: Innovation, Digitalization, and Policy. *International Journal of Online and Biomedical Engineering (iJOE)*, 21(10), pp. 37–47. <https://doi.org/10.3991/ijoe.v21i10.56737>

Article submitted 2025-05-08. Revision uploaded 2025-06-11. Final acceptance 2025-06-11.

© 2025 by the authors of this article. Published under CC-BY.

examines nine Chinese regions, which include both advanced metropolitan areas with modern digital infrastructure and developing industrial zones that implement online technologies to connect their development. The research investigates digital innovation infrastructure and online engineering educational practices between eastern provinces and western provinces to show their distinct regional differences. The research demonstrates how strategic investments in online engineering education and digital technology infrastructure can minimize regional economic differences while promoting inclusive innovation-driven growth throughout China [1]. The research examines how financial backing for engineering education affects regional sustainable development by analyzing both direct and indirect effects, which encompass innovation output, digital integration, and industrial upgrading [2]. It captures regional variations: Beijing and Shanghai are innovation-driven, while Henan and Heilongjiang are industrial modernization-driven [3]. The research develops a comprehensive framework to evaluate how targeted investments in online engineering education and digital innovation platforms enhance regional economic performance and resilience. By considering online R&D collaboration, digital talent aggregation, and virtual environmental monitoring for air quality as control variables, the study explores the differentiated impacts of digital and educational interventions across various regional settings [4]. This research addresses the insufficient exploration of digital transformation within existing regional studies by specifically examining its role in enhancing innovation capabilities and driving regional economic growth through online engineering education and digital platforms. It significantly contributes to online engineering literature by investigating: (1) the mechanisms through which online engineering education influences regional innovation and economic development in China; (2) the mediating roles of digital innovation ecosystems, digital transformation processes, and industrial upgrading facilitated by online platforms; (3) the moderating effects of digitally aggregated R&D talent density and virtual environmental monitoring; (4) regional disparities, particularly the digital divide between eastern and western regions regarding educational impact; and (5) how digitalization and online engineering initiatives modify the relationship between education investment and innovation-driven regional economic growth.

2 MATERIALS AND METHODS

2.1 Analysis of prior studies and proposed assumptions

Research has demonstrated that engineering education through digital and online platforms plays a crucial role in driving sustainable economic development. The eastern coastal regions of Guangdong, Jiangsu, and Zhejiang have advanced digital infrastructure and serve as China's main digitalized areas with concentrated educational resources. The central and western regions of China, including Sichuan, Chongqing, Shanxi, and Gansu, are undergoing industrial transformation and modernization while showing promise for engineering education development. The less developed regions of Inner Mongolia and Guangxi have representative characteristics that help analyze educational investment effects on regional economic growth in resource-constrained settings. The nine selected regions served to present complete regional variations across multiple aspects, including economic development and innovation and industrial modernization. The National Bureau of Statistics of China and the Guotai An database serve as the data sources.

The existing research base shows limited focus on specific geographic areas while failing to provide comprehensive analysis of digital innovation and transformation processes [5]. The research fills these knowledge gaps through its evaluation of online engineering education platform investments on regional economic performance across nine Chinese regions from 2014 to 2024 using the regional innovation systems framework [6]. Endogenous growth theory emphasizes R&D-driven innovation, but the regional innovation system focuses on collaboration among universities, enterprises, and governments. This research contributes to the understanding of regional development by examining how these stakeholders can enhance innovation through joint knowledge exchange and R&D investment. This research provides an advanced perspective about regional development mechanisms that operate within regional innovation systems [7]. The four core path assumptions are as follows: first, engineering education promotes economic growth; second, innovation output plays a moderating role in it; third, digital integration and global connectivity enhance this impact; and fourth, the effect of education input intensity on economic outcomes is modulated by environmental quality and R&D personnel density [8].

2.2 The linkage mechanism between engineering education and economy

High-quality engineering education promotes regional economic sustainability through innovation advancement and digitalization and industrial upgrading [9]. The three intermediary factors of innovation output, digitalization, and industrial upgrading result from external influences of international openness and R&D investment [10]. R&D density together with environmental quality represents potential moderating variables. The following research hypotheses emerge from the analysis: H1: High-quality engineering education creates positive effects on regional economic growth. H2: Engineering education creates economic growth through technological innovation as its mediating factor. H3: The penetration of the digital economy within regions acts as a moderating factor between education investment and economic growth. H4: The positive relationship between engineering education and economic sustainability gets mediated by industrial upgrading.

2.3 Mechanism of control variables

This study further examines the moderating effects of external environmental variables and the availability of regional resources [11]. The air quality index (AQI), which is an indicator of ecological constraints, may reduce the attractiveness of a region to talent and workforce productivity, whereas the concentration of R&D talent, which is a reflection of regional innovative capacity, may enhance the additional benefits that can be derived from educational investments [12]. H5: Synergy among diverse stakeholders within regional innovation systems has a positive impact on regional economic expansion. H6: High R&D personnel density strengthens the positive effect of engineering education on economic output. H7: The investment in engineering education leads to regional growth through different channels: innovation-driven in developed areas and industrial modernization-driven in less developed regions. This research changes the focus from general R&D to the various impacts of RIS interactions and digital transformation on growth.

3 RESEARCH DESIGN AND INFORMATION SOURCES

The research draws from nine Chinese regions to study how excellent engineering education affects regional economic sustainability by analyzing innovation alongside digital transformation and sectoral advancement and global connectivity and urbanization. The analysis includes workforce size and R&D intensity as control variables [13]. The study has substantial implications for both national and international development strategies. Based on the aforementioned theoretical framework. The model is specified as follows model (1):

$$\begin{aligned}
 \ln(\text{econ_perf_reg}_{it}) &= \alpha + \beta_1 \ln(\text{acad_fund_reg}_{it}) + \beta_2 \ln(\text{tech_integr_reg}_{it}) \\
 &+ \beta_3 \ln(\text{creat_pat_reg}_{it}) + \gamma_1 \ln(\text{sect_adv_reg}_{it}) \\
 &+ \gamma_2 \ln(\text{glob_conn_reg}_{it}) + \gamma_3 \ln(\text{tech_dev_fund_reg}_{it}) \\
 &+ \gamma_4 \ln(\text{city_pop_ratio}_{it}) + \gamma_5 \ln(\ln_workforce_num_{it}) \\
 &+ \delta_1 \ln(\text{aq}_{it}) + \delta_2 \ln(\text{rdpc}_{it}) + \mu_{it}
 \end{aligned} \tag{1}$$

The research implements subgroup regression to study eastern–western economic differences by analyzing variables including econ_perf_reg and acad_fund_reg and tech_integr_reg and creat_pat_reg and sect_adv_reg and glob_conn_reg and tech_dev_fund_reg. The study uses city_pop_ratio to measure urbanization while workforce size gets calculated through ln_workforce_num and air quality gets evaluated using the environmental sustainability index.

According to Table 1, the dataset encompasses key variables for evaluating regional economic sustainability, utilizing the sustainable efficiency index (econ_perf_reg) as the primary metric [14]. These variables are crucial for a comprehensive assessment of factors contributing to regional economic growth and sustainability in diverse economic contexts.

Table 1. Variable names and definition

Variable Name	Definition
econ_perf_reg	• Sustainable Efficiency Index of regional sustainability
acad_fund_reg	• Higher-level education funding from grants and licensing
tech_integr_reg	• Extent of digitalization across regions
creat_pat_reg	• Engineering innovation measured by patent volume
sect_adv_reg	• Stage of sectoral composition enhancement
glob_conn_reg	• International connectivity via cross-border trade
tech_dev_fund_reg	• Innovation funding as share of total economic output
city_pop_ratio	• Share of residents living in urban areas
ln_workforce_num	• Natural log transformation of regional workforce size
aqi	• Air quality index (Environmental Sustainability Index – ESI)
rdpc	• R&D personnel density measured by TARCI

According to Table 2 the analysis was supported by PCA-driven construction of innovation indices.

Table 2. PCA Summary of innovation indices

Index	Variables	Variance Explained (%)	PCI Loadings
Policy-Tech Index	<ul style="list-style-type: none"> • dlit_it,ensp_it • scap_it • policy_it • sdgs_it 	<ul style="list-style-type: none"> • 99.71% 	<ul style="list-style-type: none"> • All approx. 0.447
IPI	<ul style="list-style-type: none"> • creat_pat_reg • acad_fund_reg • sect_adv_reg 	<ul style="list-style-type: none"> • 97.13% 	<ul style="list-style-type: none"> • creat_pat_reg:0.5752 • acad_fund_reg:0.5792 • sect_adv_reg:0.5777
ODI	<ul style="list-style-type: none"> • tech_integr_reg • glob_conn_reg 	<ul style="list-style-type: none"> • 99.02% 	<ul style="list-style-type: none"> • tech_integr_reg:0.7071 • glob_conn_reg:0.707
IRD Index	<ul style="list-style-type: none"> • tech_dev_fund_reg • rdpc 	<ul style="list-style-type: none"> • 62.97% 	<ul style="list-style-type: none"> • tech_dev_fund_reg:0.7071 • rdpc:0.7071

According to Table 2, the online policy and technology development Index comprises five indicators related to digital engineering policy, with the first principal component explaining 99.71% of the variance through evenly distributed loadings. The digital innovation performance index integrates online patent outputs and virtual research resources, explaining 97.13% of variance with high factor loadings. The digital integration and global connectivity index assesses online technology adoption and international digital linkages, explaining 99.02% of variance with uniform loadings. The online innovation R&D intensity index, assessing digital investment intensity, accounts for 62.97% of variance with balanced contributions from its variables.

Table 3. Cluster summary: Innovation indicators

Cluster Statistic	Econ_Perf	Tech_Integr	Sect_Adv	Glob_Conn	DigitalInput
1	1.81	28.55	0.73	2.11	0.41
	0.39	6.76	0.04	0.55	0.05
	0.99	14.59	0.64	0.86	0.3
	2.51	41.48	0.8	3.04	0.51
	59	59	59	59	59
2	1.84	29.46	0.74	2.13	0.41
	0.63	9.69	0.06	0.79	0.08
	0.87	13.13	0.64	0.9	0.3
	2.73	41.78	0.81	3.03	0.5
	27	27	27	27	27
3	1.25	19.23	0.67	1.33	0.33
	0.21	3.2	0.02	0.29	0.03
	0.93	14.08	0.64	0.81	0.29
	1.55	23.78	0.71	1.75	0.38
	13	13	13	13	13
Total	1.75	27.57	0.73	2.01	0.4
	0.49	8	0.05	0.65	0.06
	0.87	13.13	0.64	0.81	0.29
	2.73	41.78	0.81	3.04	0.51
	99	99	99	99	99

The results presented in Table 3 indicate that Cluster 1 exhibits high levels of online technology integration at 28.55, strong global digital connectivity at 2.11, and moderate economic performance at 1.81. Cluster 2 achieves the highest economic outcomes and scores the highest in digital technology integration at 29.46. Conversely, Cluster 3 lags significantly, showing the lowest values across all indicators, particularly online technology integration at 19.23 and economic performance at 1.25. Overall cluster performance demonstrates balanced averages across the observed metrics. The application of LASSO regression clarified the digital clustering patterns by identifying key drivers influencing these clusters. Detailed findings from the LASSO model parameter path and optimization analysis are presented, with the subsequent section providing insights into crucial cluster drivers and parameters selected through this regression technique.

Table 4. LASSO model cross validation results and lambda selection

ID	Description	Lambda(Penalty Parameter)	Nonzero Coefficients	Out-of-Sample R ²	CV Error(Cross-Validation Error)
1	First lambda	0.47	0	-0.04	0.24
45	Lambda before optimal value	0.01	7	0.97	0.01
46	Selected optimal lambda (λ^*)	0.01	7	0.97	0.01
47	Lambda after optimal value	0.01	7	0.97	0.01
53	Last lambda	0	7	0.96	0.01

According to Table 4, the LASSO model cross-validation results indicated an optimal penalty parameter value of 0.01, yielding seven non-zero coefficients relevant to online engineering variables. The model achieved a robust cross-validated R-squared value of 0.97 with a minimal prediction error of 0.01, confirming stable predictive performance. Conversely, using a significantly larger initial lambda value resulted in no variables being selected and an R-squared value of -0.04, underscoring the importance of appropriately calibrating the model in digital innovation and online engineering contexts.

This study used 2014–2024 panel data from nine Chinese regions, comprising 99 observations. Missing values were addressed via linear interpolation [15]. To conduct the data analysis, please refer to the following description and analysis:

Table 5. Descriptive statistics of variable

Variable	Count	Mean	Std	Min	25%	50%	75%	Max
Sustainable Efficiency Index (econ_perf_reg)	99	1.75	0.49	0.87	1.32	1.75	2.13	2.73
Higher-level education funding (acad_fund_reg)	99	96.94	9.57	80	89	97	104.5	114
Extent of digitalization (tech_integr_reg)	99	27.57	8	13.13	20.81	27.77	34.49	41.78
Engineering innovation measured by patent volume (creat_pat_reg)	99	2266.78	634.37	1027	1741	2271	2787	3373

(Continued)

Table 5. Descriptive statistics of variable (Continued)

Variable	Count	Mean	Std	Min	25%	50%	75%	Max
Stage of sectoral composition enhancement (sect_adv_reg)	99	0.73	0.05	0.64	0.69	0.73	0.77	0.81
International connectivity via cross-border trade (glob_conn_reg)	99	2.01	0.65	0.81	1.45	1.97	2.56	3.04
Innovation funding as share of total economic output (tech_dev_fund_reg)	99	2.48	0.96	0.76	1.67	2.51	3.32	4.05
Share of residents living in urban areas (city_pop_ratio)	99	0.68	0.08	0.54	0.61	0.68	0.74	0.82
Natural log of regional workforce size (ln_workforce_num)	99	9	0.33	8.23	8.72	8.99	9.27	9.63
Air quality index (AQI)	99	77.02	18.91	49.63	63.1	72.5	90.75	125.42
R&D personnel density(rdpc)	99	0.01	0.01	0	0	0.01	0.01	0.03

According to Table 5, the descriptive statistics show that there are regional differences in economic performance, innovation, and technology. Section 2 examines the direct effect of academic funding on economic performance in order to investigate the impact of engineering education on these outcomes.

The average regional economic performance score reaches 1.75 according to Table 5 because regions with major investments in online engineering education and digital technology outputs achieve this level. The average air quality measurement stands at 77.02 while ranging between 49.63 and 125.42, which negatively affects productivity and innovation, thus demonstrating the need for virtual environmental monitoring systems. The average funding for digital and online engineering platforms reaches 96.94, which indicates uniform regional support. The average technological development funding stands at 2.48, which supports digital transformation and industrial upgrading efforts. The technological integration index shows an average of 27.57, which demonstrates how well online engineering education systems match their practices to digital industry requirements. The mean regional patent output of 2266.78 demonstrates that online engineering education drives positive regional innovation outcomes [16].

Table 6. Direct effects of education support on regional growth (controlling for mediators)

Coefficient	Std. Error	T-Value	P-Value	95% CI Lower	95% CI Upper	Effect Type	Direct Path
0.04	0	10.55	<0.001	0.03	0.04	Direct	Academic Funding to Economic Performance via Creat_pat_reg (Engineering innovation measured by patent volume)
0.03	0	5.45	<0.001	0.02	0.04	Direct	Academic Funding to Economic Performance via Tech_integr_reg (Extent of digitalization)
0.04	0	9.58	<0.001	0.03	0.05	Direct	Academic Funding to Economic Performance via Sect_adv_reg (Stage of sectoral composition enhancement)
0.02	0.01	4.12	<0.001	0.01	0.03	Direct	Academic Funding to Economic Performance via Tech_dev_fund_reg (Innovation funding as share of total economic output)

According to Table 6, the statistical correlations demonstrating indirect effects are detailed in Table 3 according to Model (1). This model specifically investigates the direct impacts of online engineering education funding (AFR) on regional economic sustainability (EPR), accounting for various digital innovation mediators. The findings reveal statistically significant positive impacts at the 0.001 significance level, with coefficients ranging from 0.02 to 0.04. These results robustly confirm AFR's direct influence on regional economic sustainability through multiple digital innovation pathways.

4 RESULTS

Table 7. Results of direct effect test

Direct Path	Coefficient	Std. Error	T-value	P-value	95% CI Lower	95% CI U	Effect Type
Academic Funding (AFR) to Economic Performance (EPR) via international connectivity (glob_conn_reg)	0.03	0	6.24	<0.001	0.02	0.04	Direct
Academic Funding (AFR) to Economic Performance (EPR) via Urbanization (city_pop_ratio)	0.02	0.01	3.57	<0.001	0.01	0.03	Direct
Academic Funding (AFR) to Economic Performance (EPR) via Workforce Size (ln_workforce_num)	0.04	0	12.39	<0.001	0.03	0.04	Direct
Academic Funding (AFR) to Economic Performance (EPR) via Air Quality Index (aqi)	0.05	0	40.8	<0.001	0.05	0.05	Direct
Academic Funding (AFR) to Economic Performance (EPR) via R&D Personnel Density (rdpc)	0.05	0	43.88	<0.001	0.05	0.05	Direct

The results in Table 7 demonstrate that the direct impact of funding for online engineering education (AFR) on regional economic sustainability (EPR) remains positive and statistically significant across all examined models, even after accounting for variables such as digital global connectivity, urbanization levels, workforce size, digitally monitored air quality, and R&D talent density. The coefficients, significant at the $p < 0.001$ level, range between 0.02 and 0.05, confirming the consistent positive influence of online engineering education investments on regional economic outcomes [17].

5 DISCUSSION

The research demonstrates how online engineering education platforms drive regional economic development through innovation and digitalization and sectoral advancement [18]. The study shows that digitally monitored air quality, together with digital R&D talent density and urbanization, act as external factors. The research differs from previous studies that concentrated on Shanghai as a developed area because it demonstrates how online engineering education drives industrial modernization, particularly in underdeveloped regions [19]. The implementation of digital education policies which match local requirements leads to better regional economic results [20]. Beijing should develop globally competitive digital ecosystems

according to recommendations, while Henan and Heilongjiang should use digital education to support industrial development. Future research needs to analyze both time-dependent and industry-specific patterns in digital transformation processes.

6 CONCLUSION

The study shows that advanced online engineering education drives sustainable regional economic development in China through direct effects and through digital innovation and technological integration and industrial upgrading [21]. The analysis shows that targeted investments in online engineering education boost regional economic performance through digital mediating mechanisms according to the regional innovation systems framework [22]. The analysis shows that eastern China uses digital innovation to drive growth, but Henan and other regions apply online engineering education to transform their industrial sectors [23]. The control variables of digitally monitored air quality and R&D personnel density show the intricate nature of regional dynamics. The research suggests that educational investments should match industrial requirements while enhancing digital industry-university-research collaboration [24]. The research demonstrates that digital infrastructure development and environmental management improvement should be integrated into educational and economic policies for regions with ecological challenges and low digitalization levels. Future research needs to investigate how online engineering education affects different sectors and how its effects change over time.

7 AUTHORSHIP

All authors jointly discussed and decided upon authorship. Cai Wei was responsible for the conception, design, drafting of the manuscript, and final submission as the corresponding author. Sufian Jusoh was responsible for data acquisition and analysis. Radin Siti Aishah Radin A Rahman handled the interpretation of standard academic terminology. Wang Si Ya performed format proofreading. Cai Wei is the first author and the corresponding author. Sufian Jusoh is the second author. Radin Siti Aishah Radin A Rahman is the third author. Wang Si Ya is the fourth author.

8 ACKNOWLEDGMENTS

I am grateful to Professor Sufian Jusoh for his guidance and support, and to Dr. Radin Siti Aishah Radin A Rahman and Wang Si Ya for their valuable encouragement.

9 REFERENCES

- [1] J. Tang, "New quality productivity and china's strategic shift towards sustainable and innovation-driven economic development," *Journal of Interdisciplinary Insights*, vol. 2, no. 3, pp. 36–45, 2024. <https://doi.org/10.5281/zenodo.13845756>
- [2] Y. Wei, Z. Meng, N. Liu, and J. Mao, "Research on the impact of hard technology innovation on the high-quality development of SRDI enterprises: Based on the moderating role of digital transformation," *Asia Pacific Journal of Innovation and Entrepreneurship*, vol. 19, no. 1, pp. 24–41, 2025. <https://doi.org/10.1108/APJIE-04-2024-0069>

- [3] L. Wang and J. Shao, "Can digitalization improve the high-quality development of manufacturing? An analysis based on Chinese provincial panel data," *Journal of the Knowledge Economy*, vol. 15, pp. 2010–2036, 2024. <https://doi.org/10.1007/s13132-023-01356-z>
- [4] B. Li and C. Kang, "Research on the contribution of higher education to the sustainable development of the economy in China: An empirical analysis based on provincial panel data from 2014 to 2023," *Sustainability*, vol. 17, no. 3, p. 1024, 2025. <https://doi.org/10.3991/ijep.v12i3.28253>
- [5] Z. Zulpykhar, K. Kariyeva, A. Sadvakassova, R. Zhilmagambetova, and S. Nariman, "Assessing the effectiveness of personalized adaptive learning in teaching mathematics at the college level," *International Journal of Engineering Pedagogy*, vol. 15, no. 4, pp. 4–22, 2025. <https://doi.org/10.3991/ijep.v15i4.52797>
- [6] X. Han and H. Feng, "The impact of foreign R&D on the innovation performance of China's high-tech industry and its spatial spillover effect," *PLoS ONE*, vol. 18, no. 3, p. e0282626, 2023. <https://doi.org/10.1371/journal.pone.0282626>
- [7] M. Gottlieb and M. C. Utesch, "Publish or perish: A scientific blueprint for a journal article," *International Journal of Engineering Pedagogy (ijEP)*, vol. 12, no. 3, pp. 171–177, 2022. <https://doi.org/10.3991/ijep.v12i3.28253>
- [8] X. Yu and K. Wan, "How does the selection of national development zones affect urban green innovation?-Evidence from China," *PLoS ONE*, vol. 17, no. 8, p. e0268111, 2022. <https://doi.org/10.1371/journal.pone.0268111>
- [9] V. Vass, "Research-based practice on the implementation of a brand building program in higher education: A case study," *International Journal of Advanced Corporate Learning (ijAC)*, vol. 18, no. 3, pp. 78–88, 2025. <https://doi.org/10.3991/ijac.v18i3.52967>
- [10] H. Xiang, M. Lou, and X. Fu, "Innovative models of student entrepreneurship education supported by mobile technology in higher education," *International Journal of Interactive Mobile Technologies (ijIM)*, vol. 19, no. 10, pp. 56–70, 2025. <https://doi.org/10.3991/ijim.v19i10.55839>
- [11] C. A. A. Serna, "Mitigating the risk of knowledge leakage in knowledge intensive organizations: A mobile device perspective," *arXiv preprint arXiv:2308.09229*, 2023. <https://doi.org/10.48550/arXiv.2308.09229>
- [12] N. M. G. B. da Costa, E. Marçal, R. B. Azevedo, B. L. S. dos Santos, and M. M. de Carvalho, "Evaluating cognitive aspects of ADHD students using brain-computer interface and a digital game: A study in Brazil," *International Journal of Emerging Technologies in Learning (ijET)*, vol. 20, no. 1, pp. 23–32, 2025. <https://doi.org/10.3991/ijet.v20i01.51403>
- [13] Y. Zhao, X. Kong, M. Ahmad, and Z. Ahmed, "Digital economy, industrial structure, and environmental quality: Assessing the roles of educational investment, green innovation, and economic globalization," *Sustainability*, vol. 15, no. 3, p. 2377, 2023. <https://doi.org/10.3390/su15032377>
- [14] Y. Liu, Y. Yang, H. Li, and K. Zhong, "Digital economy development, industrial structure upgrading and green total factor productivity: Empirical evidence from China's cities," *International Journal of Environmental Research and Public Health*, vol. 19, no. 4, p. 2414, 2022. <https://doi.org/10.3390/ijerph19042414>
- [15] Q. Liang and F. Yin, "Measurement and evaluation of the modernization development level of higher education in China: Based on panel data analysis of 31 provinces from 2012 to 2022," *Sustainability*, vol. 16, no. 17, p. 7250, 2024. <https://doi.org/10.3390/su16177250>
- [16] X. Guo, J. Yang, Y. Shen, and X. Zhang, "Impact on green finance and environmental regulation on carbon emissions: Evidence from China," *Frontiers in Environmental Science*, vol. 12, p. 1307313, 2024. <https://doi.org/10.3389/fenvs.2024.1307313>

- [17] K. Lv, A. Yu, S. Gong, M. Wu, and X. Xu, "Impacts of educational factors on economic growth in regions of China: A spatial econometric approach," *Technological and Economic Development of Economy*, vol. 23, no. 6, pp. 827–847, 2017. <https://doi.org/10.3846/20294913.2015.1071296>
- [18] E. Li, Y. Tang, Y. Zhang, and J. Yu, "Mechanism research on digital inclusive finance promoting high-quality economic development: Evidence from China," *Heliyon*, vol. 10, no. 3, 2024. <https://doi.org/10.1016/j.heliyon.2024.e25671>
- [19] K. Sisamud, P. Chatwattana, and P. Piriyasurawong, "The outcomes of project-based learning system on metaverse through design thinking for buddhism innovators," *International Journal of Engineering Pedagogy (ijEP)*, vol. 15, no. 1, pp. 56–74, 2025. <https://doi.org/10.3991/ijep.v15i1.51461>
- [20] N. El Rhezzali, I. Hilal, and M. Hnida, "Optimizing cheating detection in online exams with K-Shingling, MinHashing, and LSH: A comparative analysis with TF-IDF and BoW," *International Journal of Engineering Pedagogy (ijEP)*, vol. 15, no. 4, pp. 40–56, 2025. <https://doi.org/10.3991/ijep.v15i4.54419>
- [21] Y. Xie and M. Zhang, "Synergy of higher education resources and digital infrastructure construction in China: Regional differences, dynamic evolution and trend forecasting," *PLoS ONE*, vol. 19, no. 6, p. e0304613, 2024. <https://doi.org/10.1371/journal.pone.0304613>
- [22] A. A. Akaev, D. N. Desyatko, A. A. Petryakov, and A. I. Sarygulov, "Regional development and the education system in the context of digital transformation [Regional'noye razvitiye i sistema obrazovaniya v usloviyakh tsifrovoy transformatsii]," *Ekonomika Regiona= Economy of Regions*, vol. 16, no. 4.S. pp. 1031–1045, 2020. <https://doi.org/10.17059/ekon.reg.2020-4-2>
- [23] P. Liang, "The influence of policy investment on the sustainable development of universities in underdeveloped regions: An empirical analysis of China's higher education landscape," *Sustainability*, vol. 16, no. 18, p. 8068, 2024. <https://doi.org/10.3390/su16188068>
- [24] L. Ma, Y. Gan, and P. Huang, "Higher education investment, human capital, and high-quality economic development," *Finance Research Letters*, vol. 71, p. 106419, 2025. <https://doi.org/10.1016/j.frl.2024.106419>

10 AUTHORS

Cai Wei is with the UKM, Kuala Lumpur, Malaysia (E-mail: P118896@siswa.ukm.edu.my).

Sufian Jusoh is with the UKM, Kuala Lumpur, Malaysia.

Radin Siti Aishah Radin A Rahman is with the UKM, Kuala Lumpur, Malaysia.

Wang Si Ya is with the UKM, Kuala Lumpur, Malaysia.