Are Students Driving AI Innovation? Evidence from Higher Education

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Abstract: - The aim of this study is to empirically assess whether the regular use of AI in the educational process can be considered as an indicator of the foster of digital competencies relevant for the future labor market and innovative culture. The theoretical basis is human capital theory, within which the use of AI is interpreted as a form of early investment in digital competencies. The empirical base includes survey data from students in Kazakhstan, Poland, and Ukraine. To test the research hypothesis a parametric t-test with a threshold of 50% is used. The findings indicate that students can act as drivers of AI innovation only if artificial intelligence is widely and constantly integrated into educational practices. From a practical perspective, the results highlight the importance of educational policies focused on the development of digital competencies as a key element in shaping the innovative potential of the future labor market.

Key-Words: - artificial intelligence, digital economy, human capital, digital competencies, innovative culture, students, labor market, higher education

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1 Introduction

The development of the digital economy and the formation of an innovative culture, [1], [2], increasingly depend not only on technological infrastructure but also on the quality of human resources, [3], capable of creating, adapting, and using digital technologies. In this context, the higher education system, serving as a key mechanism for fostering the competencies of future labor market participants, [4], is acquiring a special role. Among these competencies, competencies related to the use of artificial intelligence tools are increasingly occupying a significant place, [5], [6].

Our paper builds on the results previously published in [7], [8]. The data, [7], argue that innovation is an important channel through which firms respond to labor market conditions. The accumulation of human capital allows companies to increase the value of their equity and improve performance. In turn, human capital is the value that employees provide through the application of knowledge, competencies, and experience, [7]. The empirical basis of our paper is [8]. The data of [8], prove that students do not use AI tools on a daily basis for educational purposes.

1.1 Theoretical basis of the study (Human Capital Theory)

The theoretical basis of this study is Human Capital Theory, [9], [10], [11], according to which the knowledge, competencies, and abilities acquired by an individual through education and training are viewed as a form of investment that increases their future productivity.

Human capital is a concept used by economists to denote personal qualities and competencies considered useful in the production process, [12]. Adam Smith defined human capital as "the acquired

and useful abilities of all the inhabitants or members of society", [13]. The relatively new concept, [9], emphasizes that in many cases, human capital is accumulated specifically for the nature of the task (or the competencies required to perform that task).

In the classical interpretation, human capital is formed through formal education, on-the-job training, and experience, [5], [6], [8], [14]. Research, [15], has shown a positive relationship between digital competencies and online capabilities, information advantages, and technology orientation. In the context of digital transformation, this theory is being further developed, as digital and AI competencies are becoming an independent and strategically important component of human capital.

From the perspective of human capital theory, the regular use of artificial intelligence in the educational process can be viewed as a form of early investment in digital skills. Such investments are not limited to technical mastery of tools, but include the development of analytical thinking, the ability to work with data, automate routine tasks, and interact with intelligent systems.

In this context, student experience is particularly important. Unlike established employees, students are actively fostering professional competencies and behavioral patterns that will later be transferred to the labor market. The frequency of using artificial intelligence in educational activities reflects the degree of integration of digital tools into individual educational strategies and can serve as an indicator of readiness for AI innovation.

Digital human capital associated with AI is considered a factor in increasing the innovative potential of organizations and the economy as a whole. Employees with experience using AI tools adapt more quickly to technological changes, demonstrate higher productivity, and are more engaged in innovation processes. Consequently, the accumulation of such competencies during higher education has long-term significance for the formation of an innovative culture and the sustainable development of the digital economy.

However, students' frequency of use of AI tools maynot be automatically interpreted as an indicator of a high level of digital competencies or innovative capacity. Systematic use of AI rather reflects the level of students' engagement with digital technologies and the extent of their inclusion in the digital educational practice. Within the framework of human capital theory, such interaction can be viewed as an early stage of digital human capital formation. Frequent use of AI tools increases the likelihood of accumulating relevant competencies, work experience, and familiarity with digital technologies. This study does not interpret frequency of AI use as a direct indicator of innovative capacity. Rather, it views frequency as an indirect indicator of the formation of conditions conducive to the development of digital competencies. Then, they can subsequently facilitate innovative activity at the level of both individual organizations and the economy as a whole.

This study suggests that students who regularly use artificial intelligence in their education are not passive consumers of digital technologies, but potential disseminators of innovative practices. Their educational experience forms the basis for future professional behavior focused on using AI as a tool for improving efficiency and generating innovation. In this sense, students can be viewed as one of the driving forces of digital innovation (AI innovation), indirectly influencing the development of an innovative culture in the economy.

Thus, relying on human capital theory allows us to conceptually link the use of artificial intelligence in the educational process with broader processes of digital transformation and innovative development. This theoretical framework provides the basis for formulating the research problem and subsequent analysis of empirical data aimed at assessing the role of students as bearers of digital human capital in the emerging digital economy. If students indeed develop digital human capital already during their education, this should manifest itself in statistically significant differences between groups of students with different frequencies of AI use.

The scientific novelty of the study lies in the comparative empirical analysis of students' use of AI tools in educational contexts across different countries and in an attempt to link microbehavioral practices of using AI with the formation of digital human capital and potential innovative activity.

1.2 Research hypothesis

Relying on human capital theory, the study suggests that the majority of students (>50%) actively integrate artificial intelligence into their learning, as evidenced by the statistically significant predominance of students regularly using AI.

This suggests that students can be viewed as a potential driver of AI innovation in the digital economy.

2 Problem Formulation

In the context of the digital economy and the growing role of artificial intelligence in innovation processes, there is a need to empirically assess

whether students can be considered a significant driving force for AI innovation. Human capital theory suggests that the widespread and regular use of artificial intelligence in the educational process reflects the accumulation of digital competencies that form the basis for future innovative activity in the labor market.

To formalize this problem, the study examines the proportion of students who regularly use artificial intelligence in their learning. A critical threshold of 50% is chosen. The choice of the 50% threshold was motivated by its interpretation as an indicator of a "critical mass" of the spread of a particular practice within a social group. This level is often used as a proxy for qualitative change. Here, the 50% threshold is not viewed as a strictly theoretically defined turning point. Rather, it serves as an analytical benchmark, allowing for an empirical assessment: whether students' use of AI has reached a level at which this practice can be considered a systemic, rather than fragmented, characteristic.

The research objective is to statistically test whether the proportion of students regularly using artificial intelligence exceeds the specified threshold (50%). To this end, the following statistical hypotheses are formulated:

H_0 : The average intensity of regularly using artificial intelligence by students in their learning is not statistically significantly greater than $\mu_0 = 50\%$. In other words, $\mu \leq \mu_0$.

H_1 : The average intensity of regularly using artificial intelligence by students in their learning is statistically significantly greater than $\mu_0 = 50\%$. In other words, $\mu > \mu_0$.

Hypotheses are tested using a one-sample t-test comparing the sample mean with a benchmark value ($\mu_0 = 50\%$) at a significance level of $\alpha = 0.1$ (one-tailed test). The choice of a relatively liberal significance level follows common practice in exploratory social science research, [16], where the objective is to reduce the risk of Type II error when testing directional hypotheses. Rejection of the null hypothesis and acceptance of the alternative hypothesis is interpreted as empirical confirmation of the proposition that students form mass digital human capital and can be considered a potential driving force for AI-based innovation. However, the interpretation of the results is cautious and is considered as a basis for more in-depth research.

3 Problem Solution

Our work continues and expands on the study, [8]. Our study includes qualitative (adopting a new theoretical framework) and quantitative (students from three countries were surveyed) differences. Students from Kazakhstan and Poland were added to the previously surveyed students from Ukraine. Some scientific sources classify Kazakhstan as a country that is partially part of Eastern Europe. The different socioeconomic conditions of these countries allow us to see whether differences in socioeconomic development influence students' ability to drive AI innovation.

3.1 Respondents

To study student AI usage, three Eastern European countries were selected, [17]. These were Kazakhstan, Poland, and Ukraine. The choice of countries was justified by the challenges in the Eastern European higher education market, [18]. Furthermore, the study, [8], links our work to Eastern Europe.

All students were undergraduates. Their majors were not related to computer science or artificial intelligence. The general characteristics of the respondents are presented in Table 1.

Table 1. Respondents

Indicator	Kazakhstan	Poland	Ukraine [8]
Male	154	81	88
Female	236	283	457
No answer	2	-	2
Number	392	364	547

Source: created by the authors.

Table 1 shows the total number of respondents (1,303) and gender representation, [17]. Kazakhstani students studied at Narxoz University. Polish students studied at National Louis University. Ukrainian students studied at the Khortytsia Academy (excluding college students), [8]. The number of respondents in each group is sufficient to verify statistical hypotheses at a significance level of $\alpha = 0.1$ and a sampling error of 5%, [16], [17].

The questionnaire was adopted from [19]. The questionnaire was hosted in the National Louis University cloud. Question #13 was selected for analysis: How often do you use artificial intelligence in your learning process? Students selected one of five answer options:

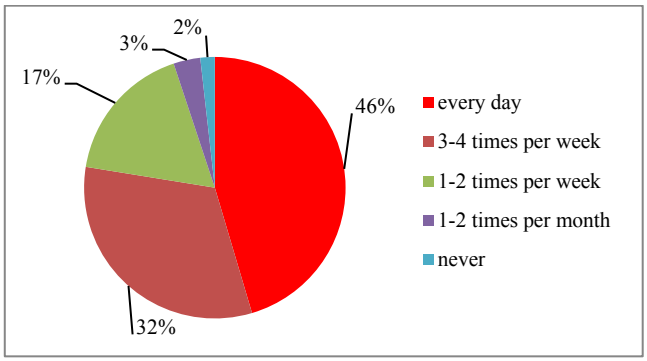
- ✓ every day
- ✓ 3-4 times per week
- ✓ 1-2 times per week
- ✓ 1-2 times per month
- ✓ Never.

The first two answer options were assigned to the group "regularly using artificial intelligence in the learning process." The third answer option was

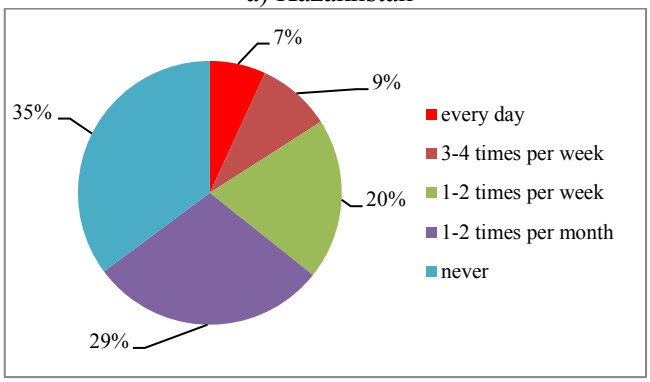
assigned to the neutral group (50%). The fourth and fifth answer options were assigned to those who use AI tools infrequently (called the control group).

3.2 Graphical and Tabular Representation of the Results

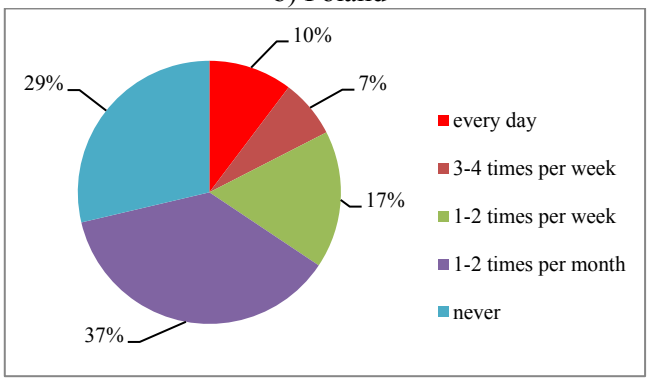
To better present the empirical results, the distribution of student responses was visualized using graphs. Figure 1 shows the structure of student use of artificial intelligence tools in three countries. This visualization allows for a qualitative comparison of the intensity of AI use and identifies differences between different educational contexts.



a) Kazakhstan



b) Poland



c) Ukraine

Fig. 1: Distribution of student answers to the research question.
Source: created by the authors.

Figure 1 shows the uneven distribution of respondents' responses across countries. It is important to note that the pie charts in Figure 1 reflect not only the proportion of students who regularly use AI. They also reflect the overall distribution of responses across frequency of use categories. This helps identify differences not only in the frequency of AI use but also in the nature of its integration into educational practice. Specifically, Figure 1 reveals whether AI use is systematic or fragmented?

While Kazakhstani students actively use AI tools (78%), this is more modest in Poland and Ukraine (16-17%). Visually, the distribution of responses for all three countries differs from 50%. But, only verification of statistical hypotheses, [17], can yield a solution with precise and predictable probability.

Thus, visualization of the empirical data allows us to preliminarily estimate the possible deviation of the response distribution from the 50% threshold. This value is used in the study as an indicator of the transition from fragmented use of AI to its systemic integration into students' educational practices.

It should be noted that the respondents' original responses were presented as an ordinal scale of AI usage frequency. For statistical analysis, these categories were approximated with numerical values (100%, 75%, 50%, 25%, 0%), allowing them to be viewed as an approximate interval scale of technology usage intensity:

- ✓ every day = 100%
- ✓ 3-4 times per week = 75%
- ✓ 1-2 times per week = 50%
- ✓ 1-2 times per month = 25%
- ✓ Never = 0%.

A similar approach is widely used in empirical studies, where frequency scales are interpreted as approximate indicators of the intensity of interaction with the technology, [17], [19]. Therefore, a one-sample t-test is used in this study to test the deviation of the sample mean from a given threshold (μ_0 = 50%). This test is used as a transparent and interpretable tool for a preliminary assessment of whether the average intensity of AI use exceeds the chosen analytical benchmark.

Statistical indicators were calculated using the Chat GPT 5.2 neural network using the methodology described in [16]. Table 2 presents the statistical indicators calculated for each respondent group.

Table 2. Statistical Indicators

Indicator	Kazakhstan	Poland	Ukraine
Sample size, N	392	364	544
Average of the sample, (Mx)	79.02	30.84	33.36
Standard deviation for sample, (δ)	23.65	30.37	31.20

Source: created by the authors.

Table 2 shows the difference in the expected value for Kazakhstan, on the one hand, and Poland and Ukraine, on the other. The standard deviation for Poland and Ukraine is larger than for Kazakhstan. This indicates a large difference in the active use of AI tools among Polish and Ukrainian students.

3.3 T-statistics: Verification of Statistical Hypotheses

Standard statistical formulas, [17], were used to verify statistical hypotheses. The presented statistical indicator values (Table 2) are used to verify statistical hypotheses. T-statistics results are presented in Table 3.

Table 3. Verification of statistical hypotheses

Indicator	Kazakhstan	Poland	Ukraine
N	392	364	544
(Mx)	79.02	30.84	33.36
(δ)	23.65	30.37	31.20
Average error, $\hat{S}_{\bar{X}}$	1.195	1.592	1.338
Value $\lvert t_{stat} \rvert$ for $\mu_0 = 50$ %	24.285	12.035	12.436
Value t_{tabl}	1.282	1.282	1.282
$\lvert t_{stat} \rvert > t_{tabl}$	Yes	Yes	Yes

Source: created by the authors.

The results of t-test show the value of $\lvert t_{stat} \rvert$ is greater than the t_{tabl} for a given number ($\mu_0 = 50\%$) for each group of respondents (Table 3). It should be noted that the initial statistical hypothesis of the study was formulated as one-tailed ($\mu > 50$), since the purpose of the analysis was to test whether the average frequency of AI use exceeds the threshold value interpreted as an indicator of the systemic diffusion of the technology.

Given that for Kazakhstan the value of M(x) is greater than the value of $\mu_0 = 50\%$, we accept the alternative hypothesis H_1 : the average intensity of regularly using artificial intelligence by students in their learning is statistically significantly greater than $\mu_0 = 50\%$. However, different results were obtained for Poland and Ukraine: the mean values were statistically significantly lower than the chosen threshold. In this case, the statistical result should be interpreted not as confirmation of the study's alternative hypothesis, but as empirical evidence that the use of AI by students in these countries has not yet reached a level corresponding to a "critical mass" of technology adoption.

The results of T-statistics allow making a decision with an precise and predictable probability.

3.4 Discussion

The obtained results demonstrate that the role of students as a potential driver of AI innovation is heterogeneous and significantly depends on the institutional and socioeconomic context.

Verification of statistical hypotheses revealed that only in the case of Kazakhstan does the proportion of students regularly using AI in their education statistically significantly exceed the threshold of 50%. This allows us to interpret the use of AI as a widespread educational practice and (in terms of human capital theory, [9], [10], [11]) as a form of accumulation of digital competencies capable of transforming into innovative potential.

At the same time, the results obtained for Poland and Ukraine point to a different picture. Despite the presence of students actively using artificial intelligence tools, their share does not statistically significantly exceed the chosen threshold (50%), indicating the fragmented and unsystematic nature of AI integration into educational practices. This result is consistent with the data from [8]. From the perspective of human capital theory, [9], [10], [11], this may indicate that the process of digital human capital accumulation in these student communities is at an earlier stage and has not yet reached the level necessary for the formation of a sustainable innovative culture.

A comparative analysis of the three countries suggests that the mere availability of artificial intelligence technologies is not a sufficient condition for their widespread use by students. Institutional factors, educational policy characteristics, and the culture of using digital tools in the educational process may play a more important role. This is consistent with broader debates in the digital economy, which suggest that the human factor, [12], [13], and the institutional environment determine the speed and depth of digital innovation, [20], [21], [22].

The significant excess of the threshold in Kazakhstan requires further explanation. One possible reason could be the active government

policy of digitalization of education and the economy. Secondly, the institutional characteristics of individual universities, including the integration of AI tools into the educational process, may play a significant role. Thirdly, this is the potentially wider use of digital technologies in students' educational activities. Finally, differences may be related to cultural and behavioral factors, [23], including the degree of students' willingness to experiment with new technological tools. These reasons are not considered in detail within the scope of this study and require further empirical analysis.

In terms of the special issue's focus, the findings highlight that digital intelligence as a driving force behind an innovative culture is not formed automatically, but rather through the accumulation of human capital in specific educational and socioeconomic contexts. Students can only act as drivers of AI innovation when the use of artificial intelligence becomes widespread and regular, extending beyond individual, fragmented and unsystematic practices.

Overall, the study's findings suggest that students have the potential to drive AI-based innovation. However, the realization of this potential varies significantly across countries. This confirms the need to consider the development of the digital economy and innovative culture through the prism of human capital formation, [9], [10], [11], [13], rather than solely through technological or infrastructural indicators, [5], [20], [24].

4 Conclusion

The aim of this study was to empirically assess whether students can be considered a driving force for AI innovation in the context of the formation of a digital economy and innovative culture. Relying on human capital theory and the results of statistical hypothesis verification, the study attempted to link the regularity of AI use in the educational process with the potential for digital competencies in the future workforce.

The results indicate that this potential is being realized unevenly. In the case of Kazakhstan, the proportion of students regularly using artificial intelligence in their education statistically significantly exceeds the 50% threshold. This allows us to interpret the use of AI as a widespread educational practice. From the perspective of human capital theory, this indicates the development of digital competencies on a scale sufficient to consider students as a potential driving force for AI innovation. However, for Poland and Ukraine, no statistically significant excess of this threshold was found, indicating a more fragmented and unsystematic nature of AI use by students.

Thus, the study's results allow us to provide a differentiated answer to the question posed in the article's title. Students can act as drivers of AI innovation only in institutional and educational settings where AI use is widespread and sustainable. Otherwise, their potential as drivers of AI innovation remains latent and does not transform into an element of innovative culture.

From a practical perspective, the findings highlight the importance of educational and innovation policies focused on the systematic integration of artificial intelligence tools into higher education curricula. The widespread and regular use of AI in the educational process creates the conditions for the development of digital human capital, which can subsequently transform into a sustainable driving force for AI innovation, including in the labor market.

However, the study has several limitations.

First, the analysis is based on student self-reports, which may be subjective in assessing the frequency of AI use.

Second, the sample only covers three Eastern European countries, limiting the generalizability of the results to other institutional and cultural contexts.

Third, using a single key indicator of AI use activity does not allow for a full assessment of the depth and quality of the digital competencies developed.

Prospects for future research primarily relate to expanding the geographic scope of the sample and including countries with different levels of digital and socioeconomic development. Of additional interest is the analysis of disciplinary differences, as well as the use of comprehensive indices of digital human capital that take into account not only the frequency but also the nature of AI use.

Finally, further research could explore the relationship between educational use of AI and the actual innovative performance of graduates in the labor market.

Thus, the obtained results make an empirical contribution to the study of the dissemination of artificial intelligence tools in higher education and show that the formation of digital human capital (using students as an example) is context-dependent and is determined by the institutional conditions of the educational environment.

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References:

[1] Mannuru, N.R., Shahriar, S., Teel, Z.A., Wang, T., Lund, B.D., Tijani, S., Pohboon, C.O., Agbaji, D., Alhassan, J., Galley, J., Kousari, R., Ogbadu-Oladapo, L., Saurav, S.K., Srivastava, A., Tummuru, S.P., Uppala, S., and Vaidya, P., "Artificial intelligence in developing countries: The impact of generative artificial intelligence (AI) technologies for development," *Information Development*, vol. 41, no. 3, pp. 1036–1054, 2023, http://dx.doi.org/10.1177/02666669231200628

[2] Prifti, V. and Sinoimeri, D., "Digital Transformation of Public Services in Albania: Evaluating the Impact of the e-Albania Platform," *WSEAS Transactions on Information Science and Applications*, vol. 22, pp. 545–551, 2025, http://dx.doi.org/10.37394/23209.2025.22.45

[3] Kristensen, P.H., "Transformative dynamics of innovation and industry: New roles for employees?," *Transfer: European Review of Labour and Research*, vol. 16, no. 2, pp. 171–183, 2010, http://dx.doi.org/10.1177/1024258910364303

[4] Layman, C.V., "Ready, Set, Design! Design Thinking: Learning to Implementation among Graduate Students," *WSEAS Transactions on Business and Economics*, vol. 22, pp. 1934–1945, 2025, http://dx.doi.org/10.37394/23207.2025.22.154

[5] Özüdoğru, G. and Durak, H.Y., "Conceptualizing pre-service teachers' artificial intelligence readiness and examining its relationship with various variables: The role of artificial intelligence literacy, digital citizenship, artificial intelligence-enhanced innovation and perceived threats from artificial intelligence," *Information Development*, vol. 41, no. 3, pp. 916–932, 2025, http://dx.doi.org/10.1177/02666669251335657

[6] Zdanevych, L., Dychkivska, I., Atroshchenko, T., Uliukaieva, I., Rozghon, V., and Reho, H., "Development of Soft Skills in Future Preschool Teachers using ICT in Their Professional Training," *WSEAS Transactions on Information Science and Applications*, vol. 22, pp. 311–325, 2025, http://dx.doi.org/10.37394/23209.2025.22.26

[7] Wang, X. and Yu, J., "Accumulating human capital: Corporate innovation and firm value," *International Review of Finance*, vol. 23, no. 4, pp. 750–776, 2023, http://dx.doi.org/10.1111/irfi.12422

[8] Nechyporenko, V., Hordiienko, N., Pozdniakova, O., Pozdniakova-Kyrbiatieva, E., and Siliavina, Y., "How often do University Students use Artificial Intelligence in Their Studies?," *WSEAS Transactions on Information Science and Applications*, vol. 22, pp. 203–214, 2025, http://dx.doi.org/10.37394/23209.2025.22.18

[9] Gibbons, R. and Waldman, M., "Task-Specific Human Capital," *American Economic Review*, vol. 94, no. 2, pp. 203–207, 2004, http://dx.doi.org/10.1257/0002828041301579

[10] Van Hiel, A., Van Assche, J., De Cremer, D., Onraet, E., Bostyn, D., Haesevoets, T., *et al.*, "Can education change the world? Education amplifies differences in liberalization values and innovation between developed and developing countries," *PLoS ONE*, vol. 13, no. 6, e0199560, 2018, http://dx.doi.org/10.1371/journal.pone.0199560

[11] Deming, D.J., "Four Facts about Human Capital," *Journal of Economic Perspectives*, vol. 36, no. 3, pp. 75–102, 2022, http://dx.doi.org/10.1257/jep.36.3.75

[12] Silva, J.A., "Human Capital," *In International Encyclopedia of Geography: People, the Earth, Environment and Technology (eds D. Richardson, N. Castree, M.F. Goodchild, A. Kobayashi, W. Liu and R.A. Marston)*, pp. 1–6, 2017, http://dx.doi.org/10.1002/9781118786352.wbieg0135

[13] Smith, A., *An Inquiry into the Nature and Causes of the Wealth of Nations*, E. Cannan, Ed., E-ISBN 978-0-226-76375-0, University of Chicago Press, 1977, http://dx.doi.org/10.7208/chicago/9780226763750.001.0001

[14] Hannemann, T., Kopáňková, N., and Surynková, P., "What helps adult learners with little formal schooling to develop basic digital skills?," *Journal of Adult and Continuing Education*, vol. 31, no. 3, pp. 561–580, 2024, http://dx.doi.org/10.1177/14779714241279356

[15] Livingstone, S., Mascheroni, G., and Stoilova, M., "The outcomes of gaining digital skills for young people's lives and wellbeing: A systematic evidence review," *New Media & Society*, vol. 25, no. 5, pp. 1176–1202, 2021, http://dx.doi.org/10.1177/14614448211043189

[16] Okulich-Kazarin, V., "Statistics Using Neural Networks in the Context of Sustainable Development Goal 9.5," Sustainability, vol. 16, no. 19, 8395, 2024, http://dx.doi.org/10.3390/su16198395

[17] Gupta, S.P., *Statistical Methods*, ISBN 13: 978818054862**.** Sultan Chand & Sons, 2011. https://books.google.gr/books/about/Statistical_Methods.html?id=fCIVEAAAQBAJ&redir_esc=y [Access Date: 24/04/2026]

[18] Okulich-Kazarin, V., "Are Students of East European Universities Subjects of Educational Services?," *Universal Journal of Educational Research*, vol. 8, no. 7, pp. 3148–3154, 2020, http://dx.doi.org/10.13189/ujer.2020.080743

[19] Okulich-Kazarin, V., Artyukhov, A., Skowron, Ł., Artyukhova, N., and Wołowiec, T., "When Artificial Intelligence Tools Meet 'Non-Violent' Learning Environments (SDG 4.3): Crossroads with Smart Education," *Sustainability*, vol. 16, no. 17, 7695, 2024, http://dx.doi.org/10.3390/su16177695

[20] Chen, X., Li, L., and Ling, X., "Research on Driving Factors of Digital Innovation in the Tourism Industry," *SAGE Open*, vol. 14, no. 4, 2024, http://dx.doi.org/10.1177/21582440241304537

[21] Hodapp, D. and Hanelt, A., "Interoperability in the era of digital innovation: An information systems research agenda," *Journal of Information Technology*, vol. 37, no. 4, pp. 407–427, 2022, http://dx.doi.org/10.1177/02683962211064304

[22] Swist, T., Collin, P., Lewis, J., Medlow, S., Williams, I., Davies C., and Steinbeck, K., "A digital innovation typology: Navigating the complexity of emerging technologies to negotiate health systems research with young people," *DIGITAL HEALTH*, vol. 9, 2023, http://dx.doi.org/10.1177/20552076231212286

[23] Okulich-Kozaryn, V., Pagava, O. and Prodan, Y., "Belief, History, and Machines: How Religious Traditions Shape Students' Attitudes Toward Artificial Intelligence," FWU Journal of Social Sciences, vol. 20, no.1, pp. 164-177, 2026, http://doi.org/10.51709/19951272/Spring2026/12

[24] Kieu, Q.T., "Insight into the demand for digital skills at the workplaces of agricultural engineering graduates in Vietnam," *Journal of Adult and Continuing Education*, vol. 30, no. 2, pp. 572–595, 2024, http://dx.doi.org/10.1177/14779714241237450

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflict of Interest

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