SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2023
ORGANIZATION AND MANAGEMENT SERIES NO. 181

HIGHER EDUCATION AND DIGITALIZATION IN PERSPECTIVE OF USE OF INTERNET, INTEGRATION OF DIGITAL TECHNOLOGY, DIGITAL PUBLIC SERVICES: PANEL STUDY OF EU NATIONS

Joanna ROSAK-SZYROCKA[1*], Simona Andreea APOSTU[2], Bulent AKKAYA[3]

[1] Department of Production Engineering and Safety, Faculty of Management Czestochowa University of Technology Poland; joanna.rosak-szyrocka@wz.pcz.pl, ORCID: 0000-0002-5548-6787
[2] Department of Statistics and Econometrics, Bucharest University of Economic Studies, Romania; Institute of National Economy, Bucharest, Romania; simona.apostu@csie.ase.ro, ORCID: 0000-0003-1727-0114
[3] Manisa Celal Bayar University, Turkey; bulent.akkaya@cbu.edu.tr, ORCID: 0000-0003-1252-9334
* Correspondence author

Purpose: Global discussion issues include managing innovation and incorporating digitalization into higher education. Combining and balancing these, digitalization may hold the key to enhancing higher education's capacity for innovation and expanding the use of cutting-edge learning technologies into their curricula, ultimately boosting student achievement. The distinctiveness of the research is on the need to improve higher education's administration, instruction, and practice via the process of innovation and digitalization of higher education. The primary goal research purpose of the study is to examine the relationships between higher education and different facets of digitalization in the context of European countries.

Design/methodology/approach: Methods used to carry out the empirical analysis were EViews 12.0, SPSS 28, and Tableau. Moreover to find out whether there is a connection between digitalization and higher education, panel regression and Granger causality were applied. Due to data accessibility, we utilized data from 31 European nations for the 2013 and 2020 empirical research relating the Digital Economy and Society Index (DESI) components and higher education.

Findings: The results suggest that every hypothesis was correct, and digitalization is crucial for higher education since it shows outstanding levels of dependability with Industry 4.0. The integration of digital technologies, internet usage, and digital public services all have a significant influence on higher education in EU nations. Additionally, studies have shown that throughout time, the higher education systems in various European nations have changed in diverse ways in terms of digitalization. As a result, the integration of higher education and innovation on a new digital foundation will support digital public services of research discoveries and creative operations of higher education institutions.

Originality/value: The challenges of the human capital required in the digital economy have received the bulk of attention in research on innovation and digitalization in higher education. In the case of European countries, there are no empirical research on the connections between elements related to digitalization and higher education. This document fills the gap in this situation. The novel of the study tackles digitalization in higher education and the need of

enhancing managers, educators, and practitioners' professional growth in higher education via the process of innovation.

Keywords: Digital University, Economy and Society Index, EViews 12.0, improvement, innovation, SPSS 28, strategic management, Tableau.

Category of the paper: research paper.

1. Introduction

Digitalization has altered the entire educational structure globally during the last decade, with practitioners, scholars, and policymakers paying close attention to educational progress (Bond et al., 2020; Pan et al., 2023; Rosak-Szyrocka, Zywiolek et al., 2022). Education is unaffected by the fast progress of technology's digitalization (Ciolacu and Svasta, 2021; Rosak-Szyrocka et al., 2024); other areas are also changing. The world's living and working standards are changing as a result of the Fourth Industrial Revolution, making many conventional educational models and teaching techniques outdated. Digital education penetrates and aids in the education of students from afar (E-learning…, 2015; Ronchi, 2019). Other areas of the industrial revolution are likewise reliant on educational structures to increase industry capabilities. The development of the educational sector was an important aspect of the industrial revolution (Jung, 2020). Regarding communication situations, accurate information, and understanding application, the educational sector has a chance to achieve a more significant aim (Information and Communication…, 2017; Measuring Teachers' Readiness…, 2020). Although knowledge will be freely accessible, comprehension and perspective on it will be required to establish innovative learning strategies. All methods and ways of life learning, distant learning, and practical learning will now have to be accommodated in traditional classroom education (Editor Academic Journals & Conferences, 2022; Tiwari et al., 2022; Wu et al., 2018). The challenges of the human capital required in the digital economy have received the bulk of attention in research on innovation and digitalization in higher education. In the case of European countries, there are no empirical research on the connections between elements related to digitalization and higher education. This document fills the gap in this situation. The novel of the study tackles digitalization in higher education and the need of enhancing managers, educators, and practitioners' professional growth in higher education via the process of innovation.

2. Literature review

The term "digitalization," often referred to as "digital transformation," refers to a business strategy that is supported by "trends related to the employment of digital technology in all sectors of human society (Stolterman, Fors, 2004). The concept of "digitalization" refers to the use of digital technology to many spheres of human existence and business across the globe. The growth of "smart cities" and "smart objects" has been linked to the rise of digitalization as one of the major themes in the development of contemporary nations (Analysis of the transformation…, 2021). The fourth industrial revolution emphasizes the use of high-speed Internet to facilitate the adoption of digital technology (Fahim et al., 2021; Feerick et al., 2022). The influence of digital technology on the learning process is enormous (Hariharasudan, Kot, 2018). Because the procedures for the expansion of the digital economy are moving more quickly, the higher education system is changing. Universities are forced to digitize their own educational, research, international, marketing, financial, and economic activities in order to maintain their competitiveness in the global market for educational services (Popelo, 2017). The use of technology in education is bringing up new avenues for learning and resource efficiency (Qureshi et al., 2021). Infrastructures on a large scale are being condensed into a single space and a single digital device. Higher education must incorporate the latest related technologies, and the Internet of Things must adapt to new methods of interacting with machines and data (Khan, Javaid, 2021). Digital technologies including artificial intelligence, cloud computing, additive manufacturing, data analytics, wireless sensor networks and social media (Lanzolla et al., 2021) are just a few examples that provide unmatched opportunities for creating and delivering distinctive products (Verganti et al., 2020). Digital product innovation is becoming a more important strategy for businesses (Nylén, Holmström, 2015). New goods or services that use or are made feasible by digital technology are known as "digital product innovations" (Lyytinen et al., 2016; Nambisan et al., 2017). The global socioeconomic issues force higher education in the twenty-first century to embrace digital technology and big data analytics in order to provide tailored learning skills via value-added intelligent educational models (Tiwari et al., 2022; Żywiołek et al., 2021). This allows for a collaborative learning environment in which academics determine the finest educational learning models. The COVID-19 virus serves as an example of how sophisticated educational technology have become one of the most important components in integrating institutions into the increasingly competitive global market (Rosak-Szyrocka, Zywiolek et al., 2022; Vargo et al., 2021; Verma et al., 2022). Digital technology is having a significant impact on education, skills, and employment. These changes highlight the growing importance of technology in education 4.0 (17th International Conference…, 2020; 2021 IEEE Global Engineering…, 2021; Effectiveness of Digital Technology, 2021; Rosak-Szyrocka, Apostu et al., 2022; Tri et al., 2021b). As a consequence of educational cooperation, digital technologies are advancing beyond cutting-edge and unconventional teaching and learning approaches. Digitalization should be incorporated into the educational institution's competitiveness strategy as well as the

state's educational policy (The shape…, 2015; Digital transformation…, 2018; Exploring digital transformation…, 2021; Popelo, 2017; Reyes Salazar et al., 2021; Rodrigues, 2017; Toader et al., 2021). The key dimensions of higher education's impact on the digital economy are shown in Table 1. In the modern world, students are used to using digital devices like smartphones, tablets, and laptops in everything from elementary school to higher education (Oztemel, Gursev, 2020; Qureshi et al., 2021). The majority of the time, people use these gadgets for communication and amusement. However, the changing world's need is for pupils to study and be educated through these technologies (Networked, Smart…, 2020; Lee et al., 2014). For trainers and instructors who have been working for a long time, understanding these gadgets is difficult. The findings of Zeehan's (Zeehan et al., 2020) study point to the difficulty of teachers' preparation for new technology. The study's conclusions also suggest that in order to enhance students' skills in digital technology education, instructors still have not properly included digital technologies into their teaching strategies. The outcomes of Zeehan research suggest that instructors' preparation for new technologies is difficult. The study's conclusions also suggest that teachers still need to do more to enhance the effectiveness of their teaching approaches by using digital technologies. The emphasis on education is shifting in the modern world to include technological learning and usability (Qureshi et al., 2021; Safiullin, Akhmetshin, 2019). When a person learns a new technology in a reasonable amount of time, they will be deemed skilled. The notion of education 4.0 (Khan, Qureshi, 2020) is a skill that is valuable now but may not be relevant tomorrow. Digital technologies that are simple, affordable, and effective will be widely used in education in the future (Rosak-Szyrocka, Blaskova, 2016; Rosak-Szyrocka et al., 2021). Therefore, education administration and learning practices must encourage vigorous improvement, exceptional service systems, resolve, particular aptitudes, access to top data and information resources, completion, alignment to excellence, continuous transformation and growth, and belief (Flexible forms…, 2018; Eglash et al., 2020). It's crucial to keep in mind that the modernization of institutions was sparked by the expansion of the digital economy. Higher education institutions need to use modern information and communication technologies into their instructional and research operations if they want to compete in the market for educational services. At this time, a lot of focus is being placed on equipping students and teachers with the digital skills they need, including providing them with gadgets and a good Internet connection. At the moment, a lot of attention is being paid to providing students and instructors with the necessary digital skills, including giving them access to devices and a reliable Internet connection. Distance and blended education are now an important aspect of every university's operations. Authors Batista et al. (2016), Bond et al. (2018), Cosmulese et al. (2019), Djakona et al. (2020, 2021), Filyppova et al. (2021), Skharlet et al. (2019), Tkalenko et al., (2017), Tømte et al. (2019), Ugur et al., (2020) have looked at the value and potential of contemporary information and communication technologies as a tactical tool to ensure that the higher education system is responsive to the demands of the digital economy (Tkalenko, 2017).

Table 1.
The key dimensions of higher education's impact on the digital economy

A characteristic of the digital economy	Impact directions on higher education's modernisation initiatives
Increasing significance of information in a nation's economic development	Increasing the demands on graduates of higher education institutions in terms of professional knowledge and abilities; encouraging lifelong learning
The role of information in a nation's economic development is becoming more important.	Intensification of knowledge and information generating processes, as well as advancements in knowledge and information transmission routes in the economy
Economic enterprises are actively incorporating information technology into their operations	Dissemination of distance education; development of future professionals' operational mastery and productive work abilities using current technologies for information and communication
The creation of an international information space	Extensive access to information technology for students, population information mobility and media literacy, the development of young people's preparation for interprofessional and interterritorial labor mobility
Increase in the proportion of information goods	Higher education institutions' focus on developing specialists for new professions, whose demand is generated by new types of economic activity
A focus on training specialists for new professions, the need for which is brought on by new sorts of economic activity, by higher education institutions	Higher education institutions should emphasize hiring IT professionals and concentrate on specialized training in information and communication technology (especially limited specialty)
Informatization, computerization	The integration of modern information and communication technology into academic procedures at universities, the development of global competencies among applicants to higher education, and the preparation of professionals to compete in a global labor market (in light of the increase in overseas work options due to the usage of Internet resources)

Source: own study base on (Popelo, 2017).

3. Data and methodology

Considering the extant literature, the subsequent hypothesis were formulated:

H1: Use of Internet significantly influences higher education.

H2: Integration of Digital Technology significantly influences higher education.

H3: Digital Public Services significantly influences higher education.

H4: The European countries evolved differently regarding digitalization and higher education across time.

The study explores the relations between higher education and digitalization components in case of European countries. Thus, higher education is represented by *tertiary education*, and digitalization is represented through three dimensions encountered also in DESI calculation: Internet using, Digital Administrative Services and Integration of Digital Technology. For Use of Internet dimension, it was used *Fixed broadband coverage*, for Integration of Digital Technology dimension it was used *E-commerce sales*, and for Digital Public Services dimension it was used *Individuals using internet in case of relationship with*

public authorities. The proportion of upper secondary, post-secondary non-tertiary, and tertiary education is reflected in the tertiary education. The E-commerce sales represents the number of enterprises registering e-commerce sales for more than 1% turnover reported to the total number of companies, except financial sector with more than 10 employees and self-employed persons. The Fixed broadband coverage represents the percentage of Fixed broadband coverage (DSL, incl. VDSL, FTTP, Cable modem DOCSIS 3.0/3.1, incl. DOCSIS 1.0/2.0, FWA) in case of householders. The proportion of people who used the internet in the last year to communicate with public authorities is shown by the Individuals utilizing the internet for engagement with public authorities. The study period was specified as 2013-2020 and all the variables were annual. All the variables are described in Table 2.

Table 2.
Dataset definition

Variables	Definition	Unit	Source
TE	Tertiary education	%	Eurostat Database
ECS	E-commerce sales	%	Eurostat Database
FBC	Fixed broadband coverage	%	Eurostat Database
IPA	Individuals using internet in case of relationship with public authorities	%	Eurostat Database

Source: own study.

The sample of the study consists of 31 European countries, according to the availability of the data. The programs SPSS 28, EViews 12.0 and Tableau were used for the empirical analysis.

In order to detect if there is a causality between digitalization and higher education it was used Granger causality and panel regression. In case of panel data, before running the panel ganger causality is necessary to verify cross-section dependence and test the stationarity using Unit root tests. To test the cross-section dependence, the most common tests are Lagrange Multiplier (LM), Pesaran's CD test, Friedman's test and Frees' test. Regarding stationarity, are used unit root tests, such as Pesaran test, Shin W-stat, Lin & Chu t test. The IPS and Levin tests imply cross-section independence in case of errors, but Pesaran (Pesaran, 2021) developed a cross-section IPS including cross-section dependence.

In case of static panel regression three different models can be used: common constant, fixed effects (FEs), and random effects (REs). There are no discrepancies between the matrices of the data in case of cross-sectional aspect when using the common constant approach (N). Differences between units may be handled by using a different intercept when FE models are employed. Interference variables may relate to time and units when the RE model is applied (Apostu et al., 2022). FE models are appropriate in case of specific set of entities and the RE model are appropriate in case inferences are based on entities randomly drawn from a large sample (Baltagi et al., 2012).

The regression equation for panel data analysis can be expressed as follows:

$$y_{it} = b_0 + b_1 x_{1it} + \cdots + b_k x_{kit} + e_{it} \quad (1)$$

where:

b_0 – cross section constant on time axis,

y_{it} – the endogenous variable,

x_{kit} – the exogenous variable, X_k, where:

$i = 1, \cdots, n$ – n represents cross sections,

$t = 1, \cdots, T$ – t represents time axis, in our case the years,

e_{it} – the error term.

In case of FEs, the model has the following form:

$$y_{it} = b_{0i} + b_1 x_1 + \cdots + b_k x_{kit} + e_{it} \quad (2)$$

The model for Res can be expressed as follows:

$$y_{it} = (b_0 + v_i) + b_1 x_{1it} + \cdots + b_k x_{kit} + e_{it} \quad (3)$$

$$y_{it} = b_0 + b_1 x_{1it} + \cdots + b_k x_{kit} + (v_i + e_{it}) \quad (4)$$

In order to select between REs and FEs it was used Hausman test and Redundant Fixed Effects test. Robustness checks imply errors heteroskedasticity, autocorrelation and dependence between the panels). For this were used the Wooldridge test (for autocorrelation). Wald test (for heteroskedasticity in case of errors), Pesaran test (for dependence among the panels in case of errors), Greene heteroscedasticity test and LM test (errors autocorrelation). In order to group the countries according to digitalization and higher education we used cluster analysis, respectively Hierarchical cluster. The homogenous groups were defined based on digitalization components and tertiary education. In cluster analysis, comparable data are grouped into uniform subsets to reveal distinctive patterns. Through remote function and grouping algorithms, the similarity between items is assessed. The similarity measures are calculated between observations and between clusters, after clusters are generated (Boccard, Rudaz, 2013). The clustering techniques assess the effectiveness of cluster configuration recovery techniques already present in the data, verifying the algorithms. Validating the algorithms reflects the methods capacity to regain cluster structures existing in the data. Statistical analyses of empirical datasets, mathematical derivations, and Monte Carlo simulation techniques are all examples of validation procedures (Milligan, Cooper, 1987). The correlation approach serves as the foundation for the hierarchical grouping algorithm (Sokal, 1958). The dendrogram, which groups all of the pieces into a single tree, illustrates the basic objective of the hierarchical grouping method. A node links two or more components, and the average of the integrated elements is used to compute the node expression profile (Eisen et al., 1998). Hierarchical Cluster Analysis identify the objects governing structure considering iterative process through objects association (agglomerative methods) or dissociation (divisive methods) (Steinbach et al., 2004).

For a certain collection of items, hierarchical cluster analysis seeks to create a hierarchically structured series of partitions; the resulting hierarchy is based on closeness measurements determined for each pair of objects (Köhn, Hubert, 2015).

Beginning with items in distinct clusters, the agglomeration process mixes the sequences until all the objects are a part of a single cluster (Almeida et al., 2007).

4. Empirical results

We employed the panel data equation model described below to address the study aim of the factors influencing high levels of education in European nations:

$$TEit = \beta it + \beta 1ECSit + \beta 2FBCit + \beta 3IPAit + \varepsilon it \quad (5)$$

The dependent variable is tertiary education The independent variables considered in the regression equations are E-commerce sales, Fixed broadband coverage, and Individuals using internet in case of relationship with public authorities. The statistics for the variables are presented in Table 3.

Table 3.
Summary statistics of dependent and explanatory variables

Variables	Mean	Std. Deviation	Min.	Max.	Skewness	Kurtosis
Tertiary education	28.950	7.242	13.800	42.800	-0.227	1.989
E-commerce sales	17.404	7.259	5.000	38.000	0.374	2.395
Fixed broadband coverage	95.732	5.120	79.100	100.000	-1.599	4.904
Individuals using the internet for interaction with public authorities	63.043	18.558	9.000	94.000	-0.513	3.098

Source: own study.

To determine the characteristics of the sampled nations, summary statistics of the data were carried out (Table 3). The average value for *tertiary education* for the European countries included in the sample is 28.95%, the minimum is 13.80%, the maximum is 42.80%, and the standard deviation is 7.24%. In the case of *E-commerce sales*, the values vary between 5% and 38%, the average is 17.40% and standard deviation of 7.26%. The average score for *fixed broadband coverage* is 95.73% with standard deviation of 5.12%, the smallest value being 79.10% and the biggest value 100%.

The percentage of people who contact with governmental authorities online ranges from 9% to 94%; the average is 63.04%, with a standard deviation of 18.56%. According to Skewness and Kurtosis values, all variables are normally distributed. Referring to the temporal axis, the variables trend are highlighted in Figure 1.

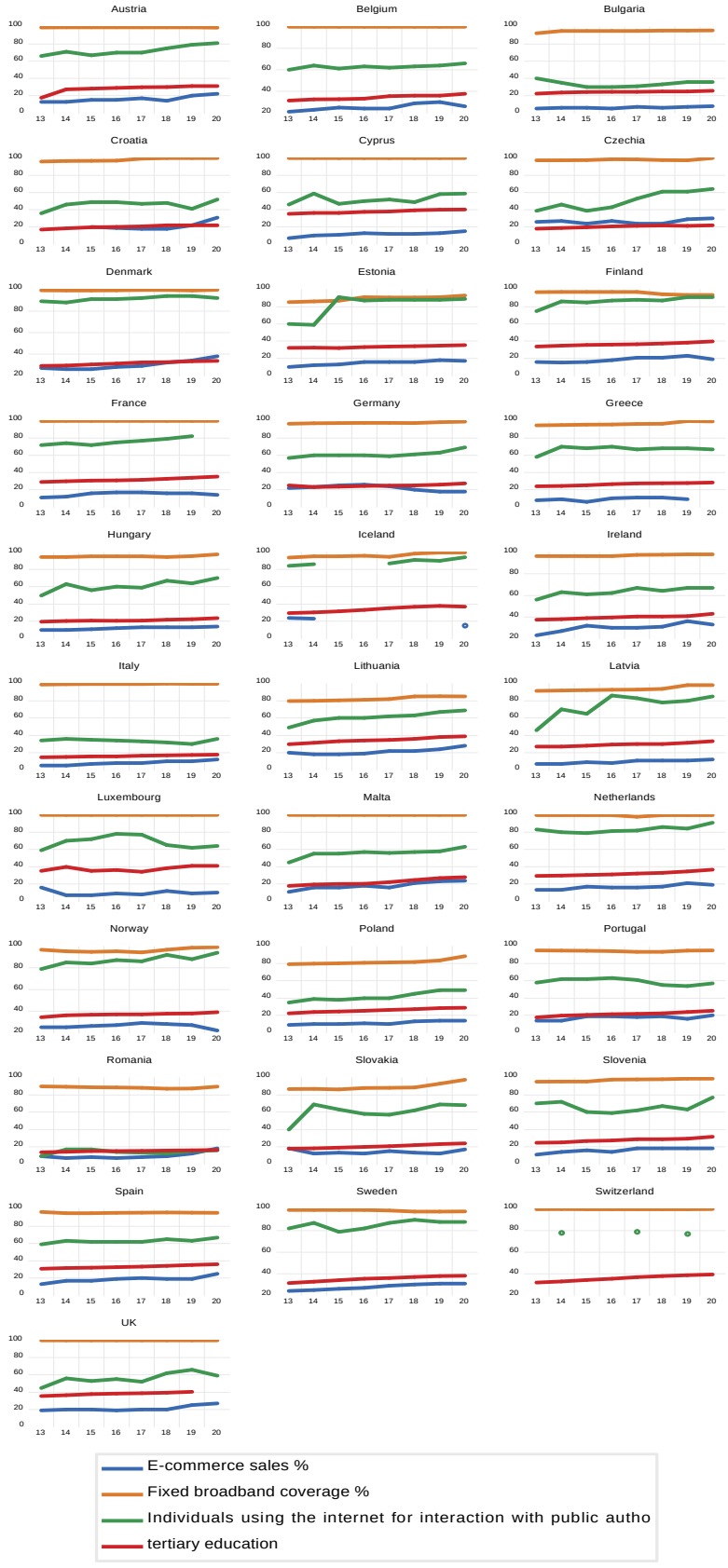


Figure 1. Variable trends.

Source: own study.

In addition, Tertiary education shows an average correlation with E-commerce sales, and Individuals using internet in case of relationship with public authorities, and a poor correlation with Fixed broadband coverage. The correlations between E-commerce sales and Fixed broadband coverage, and Individuals using internet in case of relationship with public authorities are poor (table 4). Fixed broadband coverage registers a poor correlation with Individuals using internet in case of relationship with public authorities.

Table 4.
Correlation matrix

Variables	Tertiary education	E-commerce sales	Fixed broadband coverage	Individuals using internet in case of relationship with public authorities
Tertiary education	1.000	0.417***	0.199***	0.615***
E-commerce sales	0.417***	1.000		
Fixed broadband coverage	0.199***	0.223***	1.000	
Individuals using internet in case of relationship with public authorities	0.615***	0.443***	0.275***	1.000

* 10% significance; ** 5% significance; *** 1% significance.

Source: own study.

To identify the cross-sectional dependence between variables we performed the Pesaran cross-sectional dependence test (Im et al., 2003) (Table 5). According to the results, we rejected the null hypothesis, thus there is no cross-sectional dependence, i.e., not being registered a correlation between the variables.

Table 5.
Results from testing the cross-sectional dependence

Test	Statistic	Prob.
Breusch–Pagan LM	1287.372	0.0000
Pesaran LM normal	29.967	0.0000
Pesaran CD normal	15.164	0.0000

Source: own study.

In order to test the relationship of cointegration we used the Pedroni and Kao tests for cointegration and the results confirmed the presence of a cointegration relationship among our variables (Table 6).

Table 6.
Cointegration test

Pedroni cointegration test		
Test	**Statistic**	**Prob.**
Panel v statistic	-1.178	0.881
Panel Rho statistic	3.357	0.999
Panel PP statistic	-5.753	0.000***
Panel ADF statistic	-5.049	0.000***
Group Rho statistic	5.462	1.000
Group PP statistic	-18.208	0.000***
Group ADF statistic	-8.989	0.000***
Kao cointegration test	**t-stat**	**Prob.**
ADF	-1.192	0.117 *

* 10% significance; ** 5% significance; *** 1% significance

Source: own study.

To test the variables stationarity was used unit-root tests, the results confirming all variables are stationary at level (Table 7).

Table 7.
Unit root tests

Variables	**Levin, Lin & Chu**		**Im, Pesaran & Shin W-Stat**		**DF-Fisher Chi-Square**		**PP-Fisher Chi-Square**	
	Statistic	**Prob.**	**Statistic**	**Prob.**	**Statistic**	**Prob.**	**Statistic**	**Prob.**
Tertiary education	-35.722	0.000***	-0.790	0.215	66.084	0.338	99.874	0.002***
E-commerce sales	-5.958	0.000***	0.713	0.762	57.344	0.499	105.605	0.000***
Fixed broadband coverage	-24.664	0.000***	0.317	0.624	50.732	0.797	63.475	0.455
Individuals using the internet for interaction with public authorities	-19.471	0.000***	-2.259	0.012**	123.557	0.000***	180.524	0.000***

* 10% significance; ** 5% significance; *** 1% significance

Source: own study

To test the causality the Granger causality test is employed, and the results indicate the role of Individuals using internet in case of interaction with public authorities on Tertiary education, but not vice versa. Thus, there is a unidirectional causality, flowing from Digital Public Services to high education, instead high education does not causes Digital Public Services (Table 8).

Table 8.
Granger causality results

Null hypothesis	F-statistic	Prob.
Individuals using internet in case of relationship with public authorities does not Granger Cause Tertiary education	2.301	**0.103**
Tertiary education does not Granger Cause Individuals using internet in case of relationship with public authorities	1.497	0.227
Fixed broadband coverage does not Granger Cause Tertiary education	0.831	0.437
Tertiary education does not Granger Cause Fixed broadband coverage	0.140	0.870
E-commerce sales does not Granger Cause Tertiary education	1.252	0.289
Tertiary education does not Granger Cause E-commerce sales	0.074	0.929
Fixed broadband coverage does not Granger Cause Individuals using internet in case of relationship	0.945	0.391
Individuals using internet in case of relationship with public authorities does not Granger Cause Fixed broadband coverage	0.679	0.509
E-commerce sales does not Granger Cause Individuals using internet in case of relationship with public authorities	0.632	0.533
Individuals using internet in case of relationship with public authorities does not Granger Cause E-commerce sales	0.607	0.546
E-commerce sales does not Granger Cause Fixed broadband coverage	0.022	0.978
Fixed broadband coverage does not Granger Cause E-commerce sales	0.020	0.980

Source: own study.

The panel analysis results are estimating the impact of the variables: Fixed broadband coverage, E-commerce sales, and Individuals using internet in case of relationship with public authorities on high education from a cross-sectional and longitudinal perspective. The static results using FE/RE estimations are obtained using the Hausman test (Table 9), indicating that the null hypothesis of REs is accepted, thus RE estimates are appropriate.

Table 9.
Hausman test

Test summary	Chi-Sq. Statistics	Chi-Sq. d.f.	Prob.
Cross-section random	4.504	3	0.212

Source: own study.

Furthermore, for choose Fes or REs it was used also the Redundant Fixed Effects test (Table 10). These two tests can generate contradictory results and, in this case, it can be chosen OLS model. In our case, the Redundant FEs test confirmed the random effects is appropriate for our data (Table 11).

Table 10.
Redundant Fes Tests

Test summary	Chi-Sq. Statistics	Chi-Sq. d.f.	Prob.
Cross-section F	89.216	29.197	0.000
Cross-section Chi-square	609.164	29	0.000

Source: own study.

Table 11.
Cross-section REs test comparison

Variables	Fixed	Random	Var (Diff.)	Prob.
E-commerce sales	0.319	0.311	0.000	0.411
Fixed broadband coverage	0.334	0.292	0.001	0.120
Individuals using internet in case of relationship with public authorities	0.092	0.103	0.000	0.066

Source: own study.

Static results (Table 12) indicate the relationship of digitalization with higher education. All the variables describing digitalization are positively associated with tertiary education, being statistically significant, confirming hypotheses 1-3.

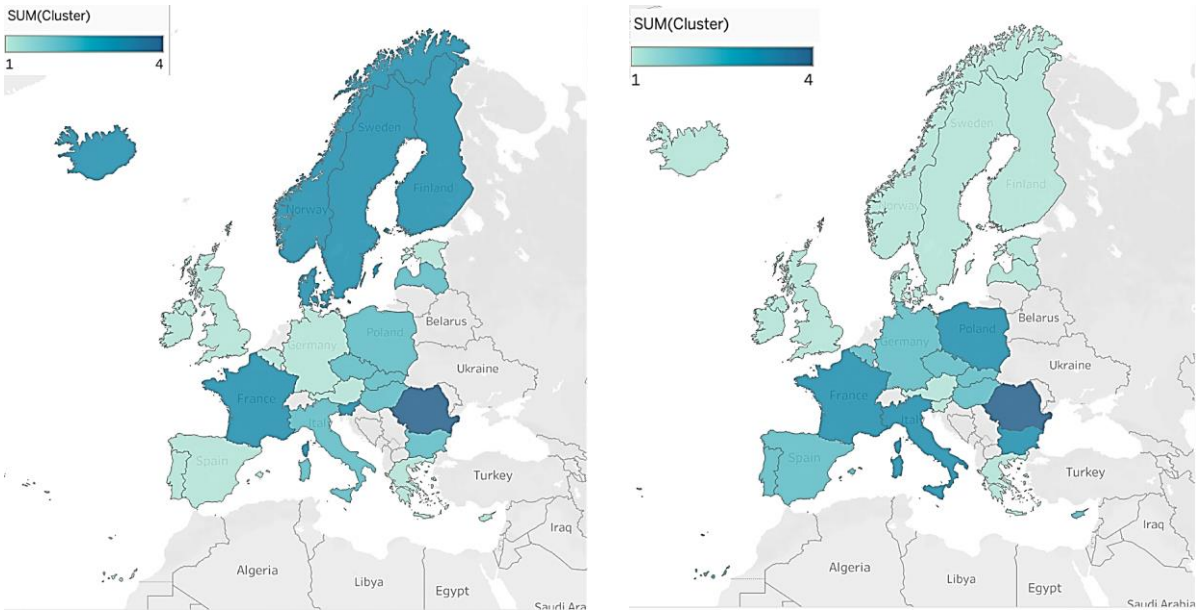
Table 12.
Statistic panel results

Variables	Coefficients	Std. Error	t-Statistic	Prob.
E-commerce sales	0.311	0.039	7.879	0.000***
Fixed broadband coverage	0.292	0.076	3.845	0.000***
Individuals using internet in case of relationship with public authorities	0.103	0.019	5.253	0.000***
Intercept	-10.945	6.065	-1.571	0.118
R^2	0.445			
F-statistic	60.430			
Prob. (F-statistic)	0.000			
Model applicability	Cross-section random			
No. of observations	230			

* 10% significance; ** 5% significance; *** 1% significance

Source: own study

Given that at the level of European countries, digitalizaton lead to a high education, the countries were clustered in this regard in 2013 and 2020 in order to identify if there are differences in those period of time. Thus, it resulted four clusters, both in 2013 and 2020 (Figure 3). The cluster 1 indicates the highest performance regarding digitalization and higher education and cluster 4 the lowest.



2013 2020

Figure 1. Resulted four clusters, both in 2013 and 2020.

Source: own study.

As it can be observed in Figure 3, In 2013 the four clusters are containing the following countries:

- cluster 1: Austria, Belgium, Cyprus, Estonia, Germany, Greece, Ireland, Lithuania, Luxembourg, Portugal, Spain, and UK,
- cluster 2: Bulgaria, Czechia, Hungary, Italy, Latvia, Malta, Poland, and Slovakia,
- cluster 3: Denmark, Finland, France, Iceland, Norway, Slovenia, Netherlands, and Sweden,
- cluster 4: Romania.

In 2020 the four clusters are presented as follows:

- cluster 1: Austria, Denmark, Estonia, Finland, Iceland, Latvia, Netherlands, Slovenia, Sweden,
- cluster 2: Belgium, Croatia, Cyprus, Czechia, Germany, Hungary, Ireland, Lithuania, Luxembourg, Malta, Portugal, Slovakia, Spain,
- cluster 3: Bulgaria, Italy, and Poland,
- cluster 4: Romania.

The clusters are different in 2020 comparing to 2013, confirming hypothesis 4.

Both, in 2013 and 2020 the cluster with lowest performance is comprising Romania. Cluster 1, the one registering the highest performance is containing, both in 2013 and 2020, Austria and Estonia. Instead, Belgium, Cyprus, Germany, Greece, Ireland, Lithuania, Luxembourg, Portugal, Spain, and UK were situated in cluster 1 in 2013, but in 2020 were situated in cluster 2, obtaining a lower performance compared to 2013. There are also different situations. For example, Denmark, Finland, Iceland, Slovenia, Netherlands, and Sweden were situated in cluster 3 in 2013, and in 2020 reached in cluster 1, improving their performance.

5. Conclusion

This study highlights the relationships between higher education and digitalization components in 31 European nations. In other words, this study shed light on multiple elements of innovation from several viewpoints that should be addressed in future higher education administration and development of digitalization capabilities and skills in academic profession. Higher education has a role in assisting a society that must adjust to digitalization and may be a beneficial addition to their productive high/hyper dynamic technology settings in the short, medium, and long term. First, the research demonstrates excellent levels of dependability with the Industry 4.0 dimensions through DESI calculation, as previously confirmed by studies (Caena, Redecker, 2019; Crawford et al., 2020; Grinberga Zalite, Zvirbule, 2020; Bullen et al., 2011).

However, in order to become a catalyst for change, higher education must also incorporate innovation into their future framework. Higher education will only be willing to work on digitalization competence if it perceives the framework as a beneficial guideline for professional innovation development. This has the potential to alter educational administration by promoting learning partnerships of innovation and digitalization inside and beyond educational environments. The manuscript aims to contribute to the academic world by evaluating the digitalization and differences in higher education institutions from 2013 to 2020. In doing so, the article includes 31 EU countries having similar education systems and international digitization processes. Furthermore, the study poses the following research question: *How to comprehend the discrepancies in higher education digitization among EU countries?* According to our research, the European countries evolved differently regarding digitalization and higher education across time. Especially, Austria, Belgium, Cyprus, Estonia, Germany, Greece, Ireland, Lithuania, Luxembourg, Portugal, Spain, and UK indicate the highest performance regarding digitalization and higher education. Crawford et al. (2020) (Caena, Redecker, 2019; Grinberga Zalite, Zvirbule, 2020; Bullen et al., 2011) and According to Márquez-Ramos (2021) digitalisation in higher education helps to bridge the divide between business and academia. Ronzhina et al. (2021) investigated digitalization of contemporary education and solutions to this gap, whereas Laufer et al. (2021) emphasized that leadership views are critical to closing this gap in digital higher education in EU member nations. Those researches support the current research hypothesis which prove that the European countries develop differently regarding digitalization and higher education across time.

Furthermore, the model verifies three hypotheses of the three research questions given in relation to the suggested sub dimension of digitalization. The first question is:

Does Use of Internet significantly influence higher education in EU countries?

It has been confirmed by encountered in DESI calculation that Use of Internet dimension that significantly influences higher education in current research. Therefore, the result is consistent with previous studies such as, Lynch et al. (2021) Billon et al. (2021) and Miranda et al. (2021) who claimed that Use of Internet dimension impacts higher education.

The second hypothesis question is:

Whether Integration of Digital Technology significantly influences higher education or not?

Other recent research demonstrating the importance of digital technology confirm this conclusion. Digital technologies fundamentally affect learning and teaching in higher education settings, and the rate of technological development creates challenge (Nikou, Aavakare, 2021). Students may continue to give information, knowledge, inspiration, and motivation by integrating high-quality education with digital technology (Bell, Jones, 2015). Higher education institutions should develop an integrated system that supports ongoing and high-quality interactive learning, taking into account technology developments and programming. Because this integration may allow higher education to broaden its instructional goals and achievements (Bozkurt et al., 2021). In conclusion, we think that the setting of higher education, the development of a set of abilities through the integration of digital technology that supports efficient and effective use of it is critical to educational achievement and lifelong learning.

According to the model's third hypothesis:

The more educators/managers promote Digital Public Services, the greater the development in digital competence in higher education.

In other words, we stated that Digital Public Services may have a direct positive influence on higher education; this discovery is in line with earlier findings from the current literature. Similarly, Kholiavko et al. (2021) demonstrated the need of recognizing the added value of using Digital Public Services from a pedagogical standpoint in order to boost effectiveness and motivation in higher education. It plays an increasingly essential function, position, and time period in the growth of each nation (Tri et al., 2021a). As a result, increasing awareness and refreshing higher education development ideas and training programs are necessary to rebuild higher education to meet labor market demands.

In light of our findings, the digitization of higher education, we established a method for measuring the extent of university integration, taking into consideration internet use, digital technology integration and public digital services and applied it to higher education learning and teaching systems. There are various advantages to digitalization in education. One of these advantages is smart learning and teaching technology. Both play an essential role in the modern university system's integration into the global educational services market. Universities should aim to build their own unique technologies that, under the impact of different risk factors, can provide a continuous learning process for students anywhere in the world in order to boost their competitiveness in global markets.

Such other researches our study has also some limitations and suggestions for future research. We believe that there are important opportunities to learn from the digitalization developments of other universities in order to strengthen our adaptation to technology and the future as a collective. We suggest new studies on these opportunities are dynamic variables and how agile managers can see them earlier and adapt them to higher education. We provide the digital process of thirty-one countries undertaken in our discussion and evaluate the innovation of higher education in relation to digitalization. But this is limited to EU countries. We recommend that future studies include other countries and test the model. However, it will also be necessary to analyze this model in perspective of developed countries in different cultures.

References

1. *17th International Conference on Information Technology–New Generations (ITNG 2020)* (2020). Cham: Springer.
2. *IEEE Global Engineering Education Conference (EDUCON)* (2021). IEEE.
3. Almeida, J., Barbosa, L., Pais, A., Formosinho, S.J. (2007). Improving hierarchical cluster analysis: A new method with outlier detection and automatic clustering. *Chemometrics and Intelligent Laboratory Systems, vol. 87, no. 2,* pp. 208-217.
4. *Analysis of the transformation of higher educational institutions through entrepreneurship in the conditions of digitalization* (2021). Available at https://search.proquest.com/openview/b4ac4e2e7a099d3cfb2b7cbd4d43fd41/1?pq-origsite=gscholar&cbl=29727.
5. Apostu, S.A., Vasile, V., Marin, E., Bunduchi, E. (2022). Factors Influencing Physicians Migration—A Case Study from Romania. *Mathematics, vol. 10, no. 3,* p. 505, DOI: 10.3390/math10030505.
6. Baltagi, B.H., Bresson, G., Pirotte, A. (2012). Forecasting with spatial panel data. *Computational Statistics & Data Analysis, vol. 56, no. 11,* pp. 3381-3397.
7. Bell, A., Jones, K. (2015). Explaining Fixed Effects: Random Effects Modeling of Time-Series Cross-Sectional and Panel Data. *Political Science Research and Methods, vol. 3, no. 1,* pp. 133-153.
8. Billon, M., Crespo, J., Lera-Lopez, F. (2021). Do educational inequalities affect Internet use? An analysis for developed and developing countries. *Telematics and Informatics, vol. 58,* p. 101521.
9. Boccard, J., Rudaz, S. (2013). Mass Spectrometry Metabolomic Data Handling for Biomarker Discovery. *Proteomic and Metabolomic Approaches to Biomarker Discovery.* Elsevier, pp. 425-445.

10. Bond, M., Buntins, K., Bedenlier, S., Zawacki-Richter, O., Kerres, M. (2020). Mapping research in student engagement and educational technology in higher education: a systematic evidence map. *International Journal of Educational Technology in Higher Education, vol. 17, no. 1*, pp. 1-30. DOI: 10.1186/s41239-019-0176-8.
11. Bond, M., Marín, V.I., Dolch, C., Bedenlier, S., Zawacki-Richter, O. (2018). Digital transformation in German higher education: student and teacher perceptions and usage of digital media. *International Journal of Educational Technology in Higher Education, vol. 15, no. 1*, pp. 1-20. DOI: 10.1186/s41239-018-0130-1.
12. Bozkurt, A., Karadeniz, A., Baneres, D., Guerrero-Roldán, A.E., Rodríguez, M.E. (2021). Artificial Intelligence and Reflections from Educational Landscape: A Review of AI Studies in Half a Century. *Sustainability*, *vol. 13, no. 2*, p. 800. DOI: 10.3390/su13020800.
13. Caena, F., Redecker, C. (2019). Aligning teacher competence frameworks to 21st century challenges: The case for the European Digital Competence Framework for Educators (Digcompedu). *European Journal of Education, vol. 54, no. 3*, pp. 356-369.
14. Ciolacu, M.I., Svasta, P. (2021). Education 4.0: AI Empowers Smart Blended Learning Process with Biofeedback. *2021 IEEE Global Engineering Education Conference (EDUCON).* IEEE.
15. Cosmulese, C.G., Grosu, V., Hlaciuc, E., Zhavoronok, A. (2019). The Influences of the Digital Revolution on the Educational System of the EU Countries. Available at https://essuir.sumdu.edu.ua/handle/123456789/74845.
16. Crawford, J., Butler-Henderson, K., Rudolph, J., Malkawi, B., Glowatz, M., Burton, R., Magni, P., Lam, S. (2020). *Journal of Applied Learning & Teaching*, *vol. 3, no. 1*, pp. 1-20. DOI: 10.37074/jalt.2020.3.1.7.
17. Digital transformation of Ukraine: challenges of theory and practice in implementation of digital quality of life (2018). *Економічний часопис, XXI*, *vol. 172, 7-8*, pp. 38-43. Available at https://www.ceeol.com/search/article-detail?id=731891.
18. Djakona, A., Kholiavko, N., Dubyna, M., Zhavoronok, A., Fedyshyn, M. (2021). E*ducational dominant of the information economy development: a case of Latvia for Ukraine*, 1728-6239. Available at https://archer.chnu.edu.ua/handle/123456789/4180.
19. Editor Academic Journals & Conferences (2022). Rapid-Adoption of E-Learning During Spread of Corona Virus (COVID-19): A Special Reference to Bangalore and Hubli City. *Central Asian Journal Of Mathematical Theory And Computer Sciences*, *vol. 3, no. 4*, pp. 74-89. DOI: 10.17605/OSF.IO/W8GX2.
20. *Effectiveness of Digital Technology in Education During COVID-19 Pandemic. A Bibliometric Analysis* (2021). Available at https://www.researchgate.net/profile/sapti-wahyuningsih/publication/351624417_the_effect_of_online_project-based_learning_application_on_mathematics_students'_visual_thinking_continuum_in_covid-19_pandemic/links/60a1ecac458515c265994bf3/the-effect-of-online-project-based-

learning-application-on-mathematics-students-visual-thinking-continuum-in-covid-19-pandemic.pdf#page=136.

21. Eglash, R., Lachney, M., Babbitt, W., Bennett, A., Reinhardt, M., Davis, J. (2020). Decolonizing education with Anishinaabe arcs: generative STEM as a path to indigenous futurity. *Educational Technology Research and Development, vol. 68, no. 3,* pp. 1569-1593. DOI: 10.1007/s11423-019-09728-6.
22. Eisen, M.B., Spellman, P.T., Brown, P.O., Botstein, D. (1998). Cluster analysis and display of genome-wide expression patterns. *Proceedings of the National Academy of Sciences, vol. 95, no. 25,* pp. 14863-14868.
23. *E-learning as an effective educational space in Poland: the benefits and disadvantages of studying using Moodle* (2015). Available at http://jamme.acmsse.h2.pl/vol73_2/73226.pdf.
24. *Exploring digital transformation in higher education and research via scenarios* (2021). Available at https://jfsdigital.org/wp-content/uploads/2021/03/06-barzman-exploring-digital-transformation-in-higher-education-ed-05.pdf.
25. Fahim, A., Addae, B.A., Ofosu-Adarkwa, J., Qingmei, T., Bhatti, U.A. (2021). Industry 4.0 and Higher Education: An Evaluation of Barriers Affecting Master's in Business Administration Enrolments Using a Grey Incidence Analysis. *IEEE Access, vol. 9,* pp. 76991-77008.
26. Feerick, E., Clerkin, A., Cosgrove, J. (2022). 'Teachers' understanding of the concept of 'embedding' digital technology in education. *Irish Educational Studies, vol. 41, no. 1,* pp. 27-39.
27. Filyppova, S., Lagodiienko, V., Duka, A., Bulyuk, V., Rybalko, S., Svinarova, H. (2021). Methodological principles of the implementation of the integrated model of the higher education competitiveness in the conditions of digital economy. *Laplage em Revista, vol. 7, 3A,* pp. 309-323. DOI: 10.24115/S2446-6220202173A1405p.309-323.
28. *Flexible forms of learning as a challenge for higher education* (2018). Available at https://www.researchgate.net/profile/lilla-korenova/publication/325723038_new_directions_in_nationwide_technology_integration_into_mathematics_teaching_the_geomatech_project/links/5b6c14d592851ca65053b3ca/new-directions-in-nationwide-technology-integration-into-mathematics-teaching-the-geomatech-project.pdf#page=14.
29. Grinberga Zalite, G., Zvirbule, A. (2020). Digital Readiness and Competitiveness of the EU Higher Education Institutions: The COVID-19 Pandemic Impact. *Emerging Science Journal, vol. 4, no. 4,* pp. 297304. DOI: 10.28991/esj-2020-01232.
30. Köhn, H.-F., Hubert, L.J. (2015). Hierarchical Cluster Analysis. *Wiley StatsRef: Statistics Reference Online,* John Wiley & Sons, Ltd, pp. 1-13.
31. Hariharasudan, A., Kot, S. (2018). A Scoping Review on Digital English and Education 4.0 for Industry 4.0. *Social Sciences, vol. 7, no. 11,* p. 227. DOI: 10.3390/socsci7110227.

32. Im, K.S., Pesaran, M., Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics, vol. 115, no. 1*, pp. 53-74.
33. *Information and communication technologies as a tool of strategy for ensuring the higher education adaptability to the digital …* Available at https://www.koreascience.or.kr/article/jako202127452890430.page.
34. *Information and Communication Technology in Education of Prospective Teachers of non-ICT Fields of Studies* (2017). Available at https://llufb.llu.lv/conference/reep/2017/latvia-univ-agricult-reep-2017_proceedings-78-83.pdf.
35. Batista, J., Morais, S., Ramos, F. *Researching the Use of Communication Technologies in Higher Education Institutions in Portugal.* Handbook of Research on Engaging Digital Natives in Higher Education Settings. IGI Global, pp. 280-303.
36. Jung, J. (2020). The fourth industrial revolution, knowledge production and higher education in South Korea. *Journal of Higher Education Policy and Management, vol. 42, no. 2*, pp. 134-156.
37. Khan, I.H., Javaid, M. (2021). Role of Internet of Things (IoT) in Adoption of Industry 4.0. *Journal of Industrial Integration and Management*, p. 2150006.
38. Lanzolla, G., Pesce, D., Tucci, C.L. (2021). The Digital Transformation of Search and Recombination in the Innovation Function: Tensions and an Integrative Framework. *Journal of Product Innovation Management, vol. 38, no. 1*, pp. 90-113.
39. Laufer, M., Leiser, A., Deacon, B., de Brichambaut, P., Fecher, B., Kobsda, C., Hesse, F. (2021). Digital higher education: a divider or bridge builder? Leadership perspectives on edtech in a COVID-19 reality. *International Journal of Educational Technology in Higher Education, vol. 18, no. 1*, p. 51. DOI: 10.1186/s41239-021-00287-6.
40. Lee, J., Kao, H.-A., Yang, S. (2014). Service Innovation and Smart Analytics for Industry 4.0 and Big Data Environment. *Procedia CIRP, vol. 16,* pp. 3-8. DOI: 10.1016/j.procir.2014.02.001.
41. Lynch, M., Sage, T., Hitchcock, L.I., Sage, M. (2021). A heutagogical approach for the assessment of Internet Communication Technology (ICT) assignments in higher education. *International Journal of Educational Technology in Higher Education, vol. 18, no. 1*, p. 55. DOI: 10.1186/s41239-021-00290-x.
42. Lyytinen, K., Yoo, Y., Boland Jr R.J. (2016) 'Digital product innovation within four classes of innovation networks. *Information Systems Journal, vol. 26, no. 1*, pp. 47-75.
43. Bullen, M., Morgan, T., Qayyum, A. (2011). Digital Learners in Higher Education: Generation is Not the Issue. *Canadian Journal of Learning and Technology / La revue canadienne de l'apprentissage et de la technologie, vol. 37, no. 1*. Available at https://www.learntechlib.org/p/42755/.
44. Márquez-Ramos, L. (2021). Does digitalization in higher education help to bridge the gap between academia and industry? An application to COVID-19. *Industry and Higher Education, vol. 35, no. 6*, pp. 630-637.

45. *Measuring Teachers' Readiness to Adopt Organizational Loyalty Philosophy* (2020). Available at https://www.researchgate.net/profile/ali-abbas-2/publication/348500642_measuring_teachers'_readiness_to_adopt_organizational_loyalty_philosophy/links/60016db445851553a0456d2a/measuring-teachers-readiness-to-adopt-organizational-loyalty-philosophy.pdf.
46. Milligan, G.W., Cooper, M.C. (1987). Methodology Review: Clustering Methods. *Applied Psychological Measurement, vol. 11, no. 4,* pp. 329-354.
47. Miranda, J., Navarrete, C., Noguez, J., Molina-Espinosa, J.-M., Ramírez-Montoya, M.-S., Navarro-Tuch, S.A., Bustamante-Bello, M.-R., Rosas-Fernández, J.-B., Molina, A. (2021). The core components of education 4.0 in higher education: Three case studies in engineering education. *Computers & Electrical Engineering, vol. 93,* p. 107278. DOI: 10.1016/j.compeleceng.2021.107278.
48. Nambisan, S., Lyytinen, K., Majchrzak, A., Song, M. (2017). Digital Innovation Management: Reinventing Innovation Management Research in a Digital World. *MIS Quarterly, vol. 41, no. 1,* pp. 223-238.
49. Ronzhina, N., Kondyurina, I., Voronina, A., Igishev, K., Loginova, N. (2021). Digitalization of Modern Education: Problems and Solutions. *International Journal of Emerging Technologies in Learning (iJET), vol. 16, no. 4,* pp. 122-135. Available at https://www.learntechlib.org/p/220004/.
50. Tkalenko, N.V., Kholiavko, N.I., Hnedina, K.V. (2017). Вектори трансформації сектору вищої освіти в умовах формування інформаційної економіки. *Науковий вісник Полісся, vol. 1, 4(12),* pp. 44-49. Available at http://journals.uran.ua/nvp_chntu/article/view/123192.
51. Networked, Smart, and Responsive Devices in Industry 4.0 Manufacturing Systems (2020). *Economics, Management, and Financial Markets, vol. 15, no. 3,* pp. 23-29. Available at https://www.ceeol.com/search/article-detail?id=895600.
52. Nikou, S., Aavakare, M. (2021). An assessment of the interplay between literacy and digital Technology in Higher Education. *Education and Information Technologies, vol. 26, no. 4,* pp. 3893-3915. DOI: 10.1007/s10639-021-10451-0.
53. Khan, N., Qureshi, M. (2020). *A Systematic Literature Review on Online Medical Services in Malaysia.* International Association of Online Engineering. Available at https://www.learntechlib.org/p/217898/.
54. Nylén, D., Holmström, J. (2015). Digital innovation strategy: A framework for diagnosing and improving digital product and service innovation. *Business Horizons, vol. 58, no. 1,* pp. 57-67. DOI: 10.1016/j.bushor.2014.09.001.
55. Popelo, O. (2017). Methodological approaches to modernization processes of the productive forces in the conditions of eurointegration. *Науковий вісник Полісся, vol. 1, 1(9),* pp. 218-224. Available at http://journals.uran.ua/nvp_chntu/article/view/101273.

56. Oztemel, E., Gursev, S. (2020). Literature review of Industry 4.0 and related technologies. *Journal of Intelligent Manufacturing, vol. 31, no. 1,* pp. 127-182. DOI: 10.1007/s10845-018-1433-8.
57. Pan, M., Zhao, X., lv, K., Rosak-Szyrocka, J., Mentel, G., Truskolaski, T. (2023). Internet development and carbon emission-reduction in the era of digitalization: Where will resource-based cities go? *Resources Policy, vol. 81,* p. 103345. DOI: 10.1016/j.resourpol.2023.103345.
58. Pesaran, M.H. (2021). General diagnostic tests for cross-sectional dependence in panels. *Empirical Economics, vol. 60, no. 1,* pp. 13-50. DOI: 10.1007/s00181-020-01875-7.
59. Qureshi, M.I., Khan, N., Raza, H., Imran, A., Ismail, F. (2021). Digital Technologies in Education 4.0. Does it Enhance the Effectiveness of Learning? A Systematic Literature Review. *International Journal of Interactive Mobile Technologies (iJIM), vol. 15, no. 4,* p. 31.
60. Reyes Salazar, M.E., Fuster-Guillén, D., Capillo Chávez, C.H., Gómez Gonzales, W.E. (2021). Creation of digital content in the oral production of english in the university higher education. *Laplage em Revista, vol. 7, 3C,* pp. 19-31. DOI: 10.24115/S2446-6220202173C1500p.19-31.
61. Rodrigues, L.S. (2017). *Challenges of digital transformation in higher education institutions: a brief discussion.* Proceedings of 30th IBIMA Conference. Available at https://recipp.ipp.pt/handle/10400.22/15234.
62. Ronchi, A.M. (2019). e-Learning: How Teaching and Training Methods Changed in the Last 20 Years. *e-Services*. Cham: Springer, pp. 69-113.
63. Rosak-Szyrocka, J., Apostu, S.A., Ali Turi, J., Tanveer, A. (2022). University 4.0 Sustainable Development in the Way of Society 5.0. *Sustainability, vol. 14, no. 23,* p. 16043. DOI: 10.3390/su142316043.
64. Rosak-Szyrocka, J., Zywiolek, J., Zaborski, A., Chowdhury, S., Hu, Y.-C. (2022). Digitalization of Higher Education Around the Globe During Covid-19. *IEEE Access, vol. 10,* pp. 59782-59791.
65. Rosak-Szyrocka, J., Żywiołek, J., Shahbaz, M. (2024). *Quality management, value creation, and the digital economy.* Abingdon, Oxon, New York, NY: Routledge.
66. Safiullin, M.R., Akhmetshin, E.M. (2019). Digital Transformation of a University as a Factor of Ensuring Its Competitiveness. *International Journal of Engineering and Advanced Technology, vol. 9, no. 1,* pp. 7387-7390.
67. Sokal, R.R. (1958). A statistical method for evaluating systematic relationships. *Univ. Kansas, Sci. Bull., vol. 38,* pp. 1409-1438. Available at https://ci.nii.ac.jp/naid/10004143217/.
68. Steinbach, M., Ertöz, L., Kumar, V. (2004). The Challenges of Clustering High Dimensional Data. *New Directions in Statistical Physics.* Berlin, Heidelberg: Springer, pp. 273-309.

69. Stolterman, E., Fors, A.C. (2004). Information Technology and the Good Life. *Information Systems Research.* Boston, MA: Springer, pp. 687-692.
70. *The shape of digital transformation: A systematic literature review* (2015). Available at https://aisel.aisnet.org/mcis2015/10/.
71. Toader, T., Safta, M., Titirișcă, C., Firtescu, B. (2021). Effects of Digitalisation on Higher Education in a Sustainable Development Framework—Online Learning Challenges during the COVID-19 Pandemic. *Sustainability, vol. 13, no. 11,* p. 6444. DOI: 10.3390/su13116444.
72. Tømte, C.E., Fossland, T., Aamodt, P.O., Degn, L. (2019). Digitalisation in higher education: mapping institutional approaches for teaching and learning. *Quality in Higher Education, vol. 25, no. 1,* pp. 98-114. DOI: 10.1080/13538322.2019.1603611.
73. Tri, N.M., Hoang, P.D., Dung, N.T. (2021). Impact of the industrial revolution 4.0 on higher education in Vietnam: challenges and opportunities. *Linguistics and Culture Review, vol. 5, S3,* pp. 1-15. DOI: 10.21744/lingcure.v5nS3.1350.
74. Ugur, N.G. (2020). Digitalization in Higher Education: A Qualitative Approach. *International Journal of Technology in Education and Science, vol. 4, no. 1,* pp. 18-25.
75. Vargo, D., Zhu, L., Benwell, B., Yan, Z. (2021). Digital technology use during COVID - 19 pandemic: A rapid review. *Human Behavior and Emerging Technologies, vol. 3, no. 1,* pp. 13-24.
76. Verganti, R., Vendraminelli, L., Iansiti, M. (2020). Innovation and Design in the Age of Artificial Intelligence. *Journal of Product Innovation Management, vol. 37, no. 3,* pp. 212-227.
77. Verma, A., Anand, D., Singh, A., Vij, R., Alharbi, A., Alshammari, M., Ortega Mansilla, A. (2022). IoT-Inspired Reliable Irregularity-Detection Framework for Education 4.0 and Industry 4.0. *Electronics, vol. 11, no. 9,* p. 1436. DOI: 10.3390/electronics11091436.
78. Wu, J., Guo, S., Huang, H., Liu, W., Xiang, Y. (2018). Information and Communications Technologies for Sustainable Development Goals: State-of-the-Art, Needs and Perspectives. *IEEE Communications Surveys & Tutorials, vol. 20, no. 3,* pp. 2389-2406.
79. Zeehan, F., Alias, R.A., Tasir, Z. (2020). Discovering Digital Technology Training Challenges for Future-Ready Educator: A Preliminary Study from Trainer Perspective. *Universal Journal of Educational Research, vol. 8, 3A,* pp. 12-23.