School digitalization indicators in educational equity analysis

Inna O. Lunina[1], Nataliia M. Nazukova[1]

[1]Institute for Economics and Forecasting of the National Academy of Sciences of Ukraine, 26, Panasa Myrnoho str., Kyiv, 01011, Ukraine

Abstract

Digital transformation of the educational landscape raises the issue of equal opportunities in education for all. National and international authorities work together on a strategy for the education system that combines equal opportunities and digitalization. Digitalization should not be seen as an end in itself. Instead, the concrete measures must be analyzed based on their contribution to equal opportunities in education. This article aims to analyze education digitalization indicators and other indicators of accessibility of education and digital key performance indicators from the point of view of their role in determining educational equity in Ukraine. The analytical tool of the principal component method was used. The main finding of the analysis is that providing households with fixed Internet and the availability of computers connected to the Internet in schools are the most essential factors of educational equity in Ukraine. This conclusion can be used to develop state digital and education policy in Ukraine.

Keywords

educational equity, digitalization indicators, digitization of general secondary education, digital accessibility, principal component method

1. Introduction

The integration of information technologies in education is taking place worldwide, in particular thanks to the support of governments for the digital transformation of education at various levels. In the conditions of digital transformation, the requirements for ensuring access to information in the learning process are put forward. An OECD study [1] reveals the impact of digitalisation on school education. It emphasises that students who do not have access to information and communication technologies will not be able to navigate the complex digital landscape and therefore will not be able to fully participate in economic, social and cultural life.

National and international policies denote serious attention to the impact of digitalisation on educational equity. The result of high-level discussions explicitly justifies the need for a strategy for an education system that combines equal opportunities and digitalisation. It is stated that concrete measures must always be analysed by their contribution to equal opportunities in education [2].

Thus, the availability of digital educational technologies, educational institutions, and teacher availability are becoming determining factors of equity in education in the modern world.

The urgency of access to education in the context of digitalisation is demonstrated by the attention paid to them at the highest level. Thus, the European Commission published the "Digital Education Action Plan (2021–2027)" which specifically notes that the creation of education and training systems adapted to the development of the digital era should be carried out to achieve more effective, sustainable and equitable development of digital education [3].

Ukraine implemented the Concept of Development of the Digital Economy and Society of Ukraine for 2018–2020 [4]. It defined the concept of the digital divide (digital inequality) as "inequalities in access to opportunities in... the educational field that exist or are exacerbated as a result of incomplete, uneven, or insufficient access to computer, telecommunication, and digital technologies" [4]. The Concept states

DigiTransfEd 2024: 3rd Workshop on Digital Transformation of Education, co-located with the 19th International Conference on ICT in Education, Research, and Industrial Applications (ICTERI 2024, September 23-27, 2024, Lviv, Ukraine

ilunina@ukr.net (I. O. Lunina); trotsn@ukr.net (N. M. Nazukova)

0000-0003-3812-4802 (I. O. Lunina); 0000-0002-5955-2032 (N. M. Nazukova)

that the reform of secondary education should meet the needs of developing the digital economy, digital society, and innovative and creative entrepreneurship. The use of digital technologies at school should be multi-platform, i.e. used not only in a computer science lesson in a separate computer science class, as usual, but during the study of other subjects, the interaction of students with each other and with teachers, real experts, conducting research, individual learning. At the same time, technologies do not replace but complement the teacher.

Ukrainian State Strategy for Regional Development until 2027 provides unimpeded high-speed Internet access for all populated areas (primarily rural and small towns) and social institutions [5]. Digital key performance indicators highly connected to educational equity are: the percentage of schools using fixed broadband Internet access in 2023 must reach 100%; the population coverage in all the territories with 4G mobile networks must reach 90%.

An essential analytical task in this regard is to incorporate education digitalisation indicators, as well as other indicators of accessibility of education and digital key performance indicators, into a single analytical model to determine their role in determining educational equity.

2. The framework and methodology of the study

The main result of the education system's functioning is the formation of human capital with a particular set of knowledge, skills and qualifications, as well as cognitive and communication skills necessary for the successful self-realisation of individuals in dynamic environments, such as the labour market or in different social groups. In the current conditions of intensification of global shocks (natural disasters, military conflicts, epidemics), and also taking into account the challenges of poor management quality, gaps in resource allocation planning and reporting on their use, an uninformative system for assessing the quality of educational services, etc., all countries face problems in the educational sphere. Despite the significant attention governments and international organisations have paid to education issues, the effectiveness of educational systems is often insufficient. Negative, economically and socially undesirable phenomena arise, such as knowledge or learning gaps, skills mismatch, lack of qualifications for the needs of the labour market, educational exclusion of specific population groups, reduction of school enrollment rates, etc. In world practice, indicators have been developed to analyse the state of educational systems, which are fairly universal evidence of the changes in the educational system. For example, the "Class size and ratio of students to teaching staff" is a D2 indicator in the OECD Educational Statistics Methodology [6]. This indicator indicates accessibility and, thus, equity of education since it reflects the ability of countries to provide the education system with a sufficient number of teachers.

Today's realities require the inclusion of educational digitalisation indicators in the analysis of educational equity. Digitalisation in the educational sphere is considered a means of solving educational problems and deepening some of them. Thus, educational digitalisation made it possible to develop educational technologies, which allowed millions of children to continue learning during the COVID-19 pandemic.

On the other hand, millions of children in the poorest countries have not received access to knowledge remotely, which has exacerbated the knowledge losses in these countries. One way or another, educational digitalisation significantly impacts educational systems, changing their landscape, the distribution of resources in the educational sector, and the educational outcomes obtained. Much hope is pinned on the digitalisation of education as a means of accelerating the acquisition and improving the quality of knowledge obtained [**?** 7], and therefore, solving the issue of the efficiency of educational expenditures.

However, digitalisation creates new challenges in the educational sphere – for example, to form a new skill of orientation in a post-truth society. Despite all the controversial views on education digitalisation, it has already become an integral part of the indicators of educational equity. In particular, we are talking about the D5 indicator – "Access to and use of information and telecommunication technologies" – according to the OECD Educational Statistics Methodology [6].

In addition to factors derived from state policy in the field of education (provision of students with teaching staff, material, technical, information and telecommunication resources), attention should also be paid to the participation of households in providing additional classes for students – tutoring or so-called "shadow education". The ability of families to finance additional educational services affects the equity of education and the educational achievements of students, that is, education outcomes [8].

Thus, for analysis, we outline three groups of educational equity factors: physical accessibility of education, digital accessibility of education, and accessibility of additional "shadow" education (figure 1).

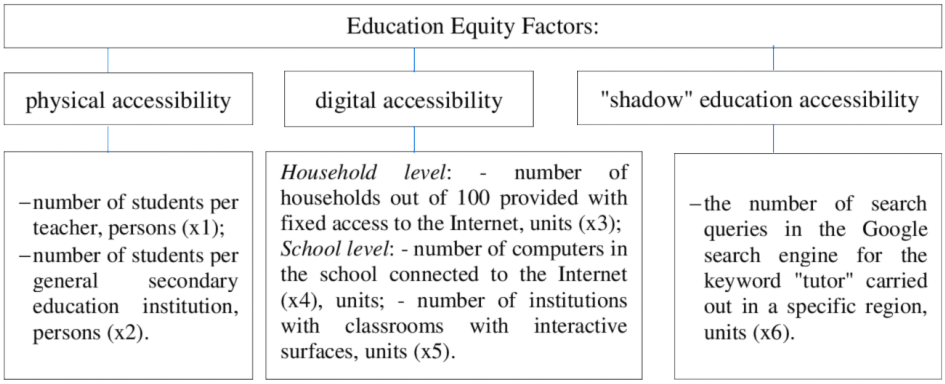

Figure 1: Grouping of education accessibility indicators into the educational equity factors.

The study measures the physical accessibility of education using the indicators of the number of students per teacher, which indicates the provision of students with teaching staff; and the number of students per general secondary education institution, which indicates the size of the school and, as a rule, indicates the material and technical support of the learning process.

The accessibility of educational digital technologies includes, in addition to the number of computers in the school connected to the Internet and the number of institutions with classrooms with interactive surfaces, the provision of households with fixed access to the Internet.

The intensity of tutoring, which indicates the accessibility of the "shadow education", is measured using the specialised Google Trends service. The measurement of "shadow" education in Ukraine using the Google Trends analytical environment is explained in the works of Sarioglo V. [9] and Khmelevska O. [10].

The study considers all the above-mentioned indicators for 2019-2022 and by region. Thus, a set of initial data for analysis consists of many variables with different units of measurement linked to each other.

The evaluation of significance and analysis of the linkages between the indicators mentioned above of education accessibility are carried out using statistical analysis methods, one of the most promising of which is the principal component method. The principal component method is a way to reduce a set of directly observed features to a smaller number of implicit but objectively existing factors. Finding the principal components is reduced to identifying linear combinations of random variables with the maximum possible variance. In other words, selecting several variables from many of them and explaining the total variance of the entire set of variables at a level of at least 90% is a practical result of using the principal component method.

The principal component method applies a mathematical procedure that transforms a set of correlated variables into a smaller number of uncorrelated variables—the principal components. Principal component number one accounts for as much of the variability in the data as possible, and each further principal component accounts for as much of the remaining variability as possible.

The principal component method is based on a linear model of the type (1) [11]:

$$y_j^{'} = \sum_{n=1}^{n} a_{jr} f_r, \tag{1}$$

where $y_j^{'}$ – is the normalized value of the j_{th} indicator; a_{jr} – is the weight of the r_{th} component in the j_{th} indicator; f_r – is the r_{th} principal component; n is the number of indicators; r, j =1, 2,…,n.

Principal component one accounts for the maximum total variance in the observed variables. This means that the first principal component will be correlated with at least some of the observed variables.

Principal component number two will account for the maximum variance in the data set not accounted for by principal component number one. This means that the second principal component will be correlated with some of the observed variables that were not strongly correlated with principal component number one.

The second principal component does not correlate with the first principal component; that is, the correlation between components one and two is zero.

Due to the relationship between the principal components and the correlation coefficients, model (1) can be rewritten in the following form (2):

$$y_j^{'} = y_{j1}v_1 + y_{j2}v_2 + y_{j3}v_3 + y_{j4}v_4, \tag{2}$$

where y_j' – is the normalized value of the j_{th} indicator; a_{j1} – is the weight of the first principal component in the j_{th} indicator; v_1 – is the value of the first principal component in the total variance of the set of observations; a_{j2} – is the weight of the second principal component in the j_{th} indicator; v_2 – is the value of the second principal component in the total variance of the set of observations; a_{j3} – is the weight of the third principal component in the j_{th} indicator; v_3 – is the value of the third principal component in the total variance of the set of observations; a_{j4} -is the weight of the fourth principal component in the j_{th} indicator; v_4 – is the value of the fourth principal component in the total variance of the set of observations.

3. Literature review

A comprehensive substantiation of the crucial role of digital technologies in Ukrainian schools during the ongoing war is given in Vorotnykova et al. [12]. As stated in the study, one of the critical advantages of digital technology usage in secondary education is that it ensures educational accessibility. Agreeing intuitively with this statement, our research proves it through statistical analysis.

Early literature on the impact of information and telecommunication on the learning process and educational outcomes suggested several opposite opinions: from the possibility that computers would replace teachers in key instructional roles to realising its' impossibility and undesirability. A comprehensive review of early research as well as results of quantitative and qualitative analysis of the impact of digitalisation on learning during 1960-2000, presented in T.S.Eng [13], resulted in several conclusions that are still relevant and that we use in our research. It is stated that higher usage of information and telecommunication positively affected school achievement both at the individual pupil level and at the school level.

More recent studies have focused on substantiating and improving information and telecommunication usage in education. For instance, Brown et. al [14] explore the factors that influence the transformative use of digital technology in schools, focusing on innovations that contribute to enhanced educational outcomes. The complexity of modern learning ecology substantiated in the study makes teachers' professional training in the digital sphere one of the central tasks ensuring "creative teaching" for "creative learning". One way to ensure a teacher's preferred style of whole-class interactive teaching is using an interactive whiteboard (IWB). As stated in R. Wood and J.Ashfield [15], IWB had enhanced whole-class teaching and learning, increasing educational accessibility. Considering the wide use of IWB in Ukraine, this tool is analysed in our research as one of the educational accessibility factors.

Physical accessibility of education, expressed via such indicators as the ratio of students per teacher or educational institution, that identify educational equity, are widely discussed in studies by E.Hanushek [16, 17], A.Krueger [18], L.Wang [19]. There is an ongoing debate on the role of teacher-pupil ratio on educational outcomes. While A. Krueger states that the difference in the ACT test scores between students from smaller and from larger classes is statistically insignificant (19.3 to 19.2, respectively),

E.Hanushek substantiates the necessity of taking into account contextual factors to make substantial conclusions, namely the teacher's quality, and L.Wang concludes, that large classes are associated with challenges in delivering high-quality and equitable learning opportunities. The study by R. Rodriguez et al. [20] underlines the impact of the class and school size on parent's engagement in the educational process. The authors state that the student-teacher ratio has the strongest impact on parents' involvement in education. This conclusion is highly consistent with other studies that reveal the role of parents' involvement in tutoring for the educational outcomes of their children (Gupta, A. [21], Ma, Y. et al. [22], Ansong, D. et al. [23]).

To take into consideration the results of the studies above and to shed some light on the role of information and telecommunication, class size, school size, and family on educational equity in Ukraine, we take into consideration such indicators: number of households provided with fixed access to the Internet, number of computers in the school connected to the Internet, number of schools with classrooms with interactive surfaces (or IWBs), number of students per teacher in school, number of students per general secondary education institution, interest in tutoring that represents parents' involvement in educational process.

This article aims to reveal the role of education digitalisation indicators in a set of education inputs identifying educational equity in Ukraine. The hypothesis is that in a speedily digitalising world, education digitalisation indicators will appear to be dominant.

4. Data and descriptive statistics

The analysis of educational equity indicators in Ukraine is carried out based on a set of relevant education accessibility indicators. We consider six indicators that correspond to the grouping of indicators of access into the educational equity factors outlined in figure 1: x1 – number of students per teacher, persons; x2 – number of students per one general secondary education institution, persons; x3 – provision of households with fixed access to the Internet, % of households in a region; x4 – number of computers in a general secondary education institution connected to the Internet, units; x5 – number of general secondary education institutions that have classrooms with interactive surface units; x6 – distribution of regions by the number of Google queries for the keyword "tutor", where 100 points are assigned to the region with the most significant number of query points.

Specific values of the indicators are obtained from official publications of the State Statistics Service of Ukraine [24, 25], Ministry of Education and Science and the Institute of Educational Analytics[26, 27] National Commission for the State Regulation of Electronic Communications, Radio Frequency Spectrum and the Provision of Postal Services[28] and Google Trends analytical tool [29].

A list of observations is given in table 1.

Note: Data for Kyiv city in 2022 are not available. The number of observations is 91 (4 years * 23 regions – 1 missing observation).

5. Results of the analysis

The selected indicators have different units and measurement scales. Therefore, it is necessary to standardise them. Standardisation of values of selected indicators [x1, x2, x3, x4, x5, x6] is carried out using formulas (3-5) [30]:

$$y_j^{'} = (x_{ji} - \overline{x_j})/\sigma_j \tag{3}$$

$$\overline{x_j} = \frac{1}{N}\sum_{i=1}^{N} x_{ji} \tag{4}$$

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{N}(x_{ji} - \overline{x_j})}{N-1}} \tag{5}$$

Table 1
General secondary education accessibility indicators in 23 regions of Ukraine in 2019-2022.

N	Region	x1	x2	x3	x4	x5	x6
1	Vinnytsia	8	203	38	8424	551	70
2	Vinnytsia	8	213	43	9100	628	47
3	Vinnytsia	9	223	48	10260	390	61
4	Vinnytsia	9	254	77	10115	353	80
5	Volyn	8	220	51	6462	457	66
6	Volyn	8	230	54	7182	502	61
7	Volyn	8	241	65	8775	215	88
8	Volyn	8	258	72	7295	237	75
9	Kyiv city	12	602	78	15596	412	51
10	Kyiv city	12	593	86	17410	434	41
.....							
88	Chernivtsi	9	255	32	5551	329	64
89	Chernivtsi	9	262	29	6199	348	47
90	Chernivtsi	9	272	37	6679	263	34
91	Chernivtsi	9	309	54	6061	247	61

where y_{ji} – is standardized values of random variables X_j at i_{th} measurement;

x_{ij} – is the values of random variables X_j at i_{th} measurement;

x_j – is the mean value of random variable X_j summarized at all i measurements;

σ_j – is the standard deviation X_j; N=91 (4 years *23 regions - 1 missing observation), j=1,2, ...6, i=1,2,...,91.

Standardised values of selected indicators are presented in table 2.

Table 2
Standardised values of 6 selected indicators of general secondary education accessibility in Ukraine in 2019-2022.

N	y1	y2	y3	y4	y5	y6
1	-0.76425242	-0.91108823	-0.97440287	-0.429695433	0.82271265	0.84592628
2	-0.61191935	-0.78732877	-0.65635889	-0.243199806	1.37110948	-0.07239514
3	-0.47922643	-0.66628640	-0.33831491	0.076822277	-0.32393528	0.48658311
4	-0.34169407	-0.28647586	1.50634016	0.036819517	-0.58745064	1.24519646
5	-1.06712740	-0.71241673	-0.14748853	-0.970974163	0.15324119	0.68621820
6	-0.87221031	-0.58781378	0.04333786	-0.772339767	0.47373284	0.48658311
7	-0.77738806	-0.44433023	0.74303461	-0.332861165	-1.57029172	1.56461261
8	-0.75998606	-0.23809897	1.18829618	-0.741165202	-1.41360691	1.04556137
9	1.97974766	3.96737034	1.56994895	1.548923859	-0.16725047	0.08731293
10	2.12547357	3.85582118	2.07881932	2.049372185	-0.01056566	-0.31195725
...	...	...	...	...	...	...
88	-0.45312396	-0.28279632	-1.35605564	-1.222301851	-0.75837952	0.60636417
89	-0.33871494	-0.18858818	-1.54688203	-1.043530894	-0.62306082	-0.07239514
90	-0.21462693	-0.07347630	-1.03801166	-0.911107963	-1.22843395	-0.59144638
91	-0.16377773	0.38559315	0.04333786	-1.081602487	-1.34238654	0.48658311

Correlation analysis of a set of standardised values of 6 indicators (table 3) shows that the Pearson correlation coefficient exceeds 0.8, which indicates the presence of collinearity [31], only between such indicators: the number of students per teacher (y1) and the number of students per one general secondary education institution (y2).

Rlab software allows us to obtain new synthetic variables – principal components f_r – from a set of standardised values (table 4) and a matrix of weight coefficients a_j of each principal component in the j-th indicator (Table 5).

The contribution of the first four principal components to the total variance of the selected set of indicators of accessibility of general secondary education in Ukraine captures 96% of the total variance

Table 3
Matrix of multiple correlation indicators of accessibility of general secondary education in Ukraine in 2019-2022.

	y1	y 2	y 3	y 4	y 5	y 6
y1	1.0000000	0.8426200	0.2293822	0.7028093	0.29892497	-0.69030856
y 2	0.8426200	1.0000000	0.3595047	0.6715199	0.21749700	-0.44107045
y 3	0.2293822	0.3595047	1.0000000	0.4906840	0.12222078	0.21292410
y 4	0.7028093	0.6715199	0.4906840	1.0000000	0.61181532	-0.21081842
y 5	0.2989250	0.2174970	0.1222208	0.6118153	1.00000000	-0.07046097
y 6	-0.6903086	-0.4410704	0.2129241	-0.2108184	-0.07046097	1.00000000

Table 4
New synthetic variables – principal components [fr1,…,fri].

	f1	f2	f3	f4	f5	f6
[1,]	-1.31844082	0.33868504	-1.391270426	-0.337617532	0.074094465	0.18057483
[2,]	-0.56903201	0.09282469	-1.674846839	0.361689952	0.304646816	-0.091171165
[3,]	-0.86641419	0.2110691	-0.14485577	-0.138944731	-0.546592223	-0.037091331
[4,]	-0.49278545	1.65255893	1.132922111	0.178398607	-0.121335556	0.246987172
[5,]	-1.59391114	0.44357719	-0.343962474	0.083244948	0.491325586	-0.035584995
[6,]	-1.13210856	0.5172127	-0.485050355	0.251245344	0.563048515	-0.035329808
……						
[87,]	-1.56143333	-0.67384119	1.108166499	0.298929791	-0.124377675	-0.031896505
[88,]	-1.71322182	-0.83831906	0.002874402	-0.895099123	0.200532672	0.285812723
[89,]	-1.31686392	-1.3392414	-0.207690683	-0.656542193	0.146556776	0.046688318
[90,]	-1.023764	-1.54803878	0.539983324	-0.236525575	-0.041101792	-0.155485469
[91,]	-0.95821858	-0.3315071	1.361083492	-0.534115156	0.429725479	0.188257834

Table 5
Weights [a1,…aj] of each principal component fr in the j-th indicator.

	a1	a2	a3	a4	a5	a6
[,1]	0.523496	0.495239	0.239484	0.495918	0.289448	-0.30598
[,2]	-0.24391	-0.07469	0.59448	0.279876	0.284487	0.649814
[,3]	0.100641	0.28541	0.497137	-0.14694	-0.79927	0.028987
[,4]	-0.03794	-0.55761	0.550815	-0.11581	0.138495	-0.593
[,5]	-0.11859	0.494016	0.195971	-0.72753	0.415824	-0.03571
[,6]	0.800517	-0.33574	0.017159	-0.33382	0.066046	0.361051

(table 6).

Table 6
Statistical description of the obtained new synthetic variables – principal components.

	(f1)	(f2)	(f3)	(f4)	(f5)	(f6)
Standard deviation	1.7710	1.176	0.9611	0.5644	0.40788	0.26788
Proportion of Variance, v_j	0.5228	0.2305	0.154	0.0531	0.02773	0.01196
Cumulative Proportion	0.5228	0.7533	0.9072	0.9603	0.98804	1.000

Therefore, to establish the relationship between the principal components and the weight coefficients based on model (1), we will use the first four values of the contribution of the principal components to the total variance of the set of observations (vj) and the corresponding first four rows of table 5. The results of calculating the normalised values of indicators of general secondary education accessibility in Ukraine in 2019-2022 are as follows:

y'1 – number of students per teacher is 0.23;

y'2 – number of students per one general secondary education institution is 0.25;

y'3 – the provision of households with fixed access to the Internet is 0.37;

y'4 – number of computers in a general secondary education institution connected to the Internet is 0.29;

y'5 – number of general secondary education institutions that have classrooms with interactive surfaces is 0.1;

y'6 – interest to the "shadow" education (tutoring) is (- 0.04).

It should be noted that the sum of the weights should not be equal to one but should be close to it [11]. In our case the sum of the weights is 1.2.

The normalised value of the sixth indicator – provision of households with fixed access to the Internet or Digital Transformation Index – has the most significant weight. Indicators of interest in the "shadow" education and equipping classes with interactive surfaces have the lowest values. It is possible to assess the change in some indicators of education accessibility compared to others using the geometric method by plotting the obtained results in the coordinates of the first two principal components. To do this, we constructed a graph in which all 91 observations regarding the accessibility of general secondary education in Ukraine in 2019-2022 are indicated by dots but not in the initial coordinates, namely in the coordinates of the first (plotted along the x-axis) and second (plotted along the y-axis) principal components (figure 2).

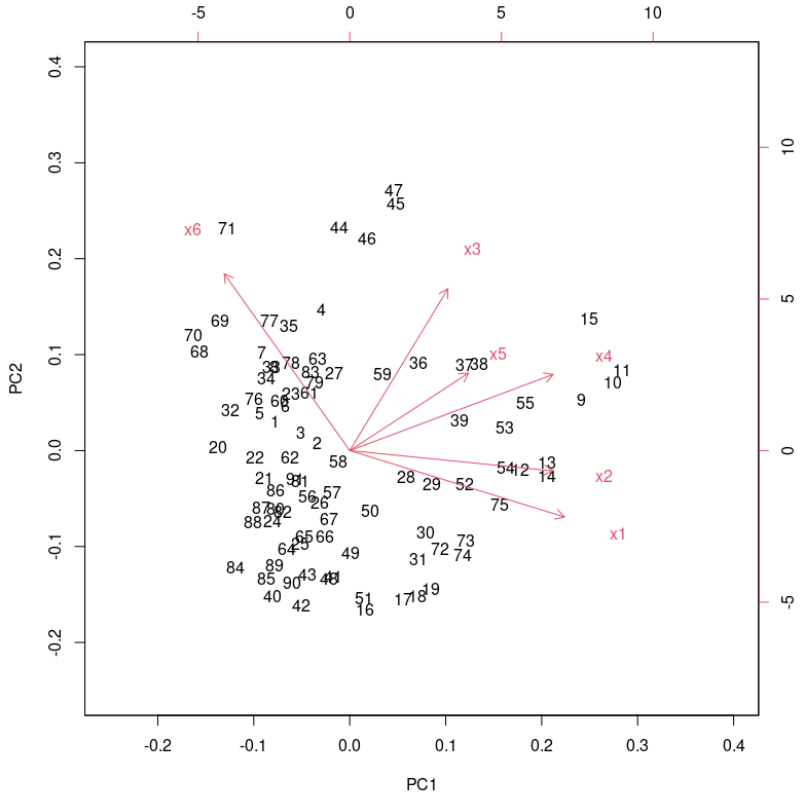

Figure 2: Results of the analysis in the coordinates of the first two principal components. Source: constructed by the authors using Rlab software.

Within the coordinates of the first two principal components, the vectors depict the direction of six indicators selected to analyse the equity of general secondary education. An important conclusion is that students' (or their families') interest in tutoring is almost the opposite of providing students with teachers and places in educational institutions.

6. Conclusions

The results of the conducted analysis show that the most critical factors of educational equity in Ukraine refer to digital accessibility – the provision of households with fixed Internet and the availability of computers connected to the Internet in schools.

This result is essential for developing state policy to improve equity in general secondary education in Ukraine. In particular, the following are essential practical conclusions:

- of the instruments of state policy to make general secondary education more equitable, the most important is providing households with fixed access to the Internet, as well as connecting school computers to the Internet;
- providing a sufficient number of school teachers reduces the burden on families with children since a decrease in the number of students per teacher will reduce interest in tutoring.

This justifies the attention paid to digitalisation in the State Strategy for Regional Development until 2027. The analysis results are consistent with the key performance indicators of the State Strategy implementation – to fully provide schools with fixed broadband Internet access and to cover the population on all the territories with 4G mobile networks. At same time, it should be noted that one of the most challenging tasks in this field is to raise teachers' digital skills. As empirical studies state, "despite the significant developments in the implementation of information and communication technologies in the educational process… the issue of the ability and maintenance of teachers' readiness to use still remains insufficiently resolved" [32]. This leaves space for further research considering teachers' digital competencies as a factor of educational equity in Ukraine.

The general conclusion is that digitalisation plays a major role in ensuring educational equity in Ukraine compared to the provision of students with teachers and places in general secondary education institutions and the participation of families in additional educational services.

References

[1] OECD, Students, Computers and Learning, 2015. URL: https://www.oecd-ilibrary.org/content/publication/9789264239555-en. doi:10.1787/9789264239555-en.

[2] Deutsche UNESO-Kommission, Für eine chancengerechte gestaltung der digitalen transformation in der bildung, 2021. URL: https://www.unesco.de/sites/default/files/2021-10/Resolution_Digitale_Transformation_Bildung.pdf.

[3] Digital Education Action Plan 2021-2027, Technical Report, European Commission, Directorate-General for Education, Youth, Sport and Culture, Brussels, 2020. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020SC0209.

[4] On approval of the Concept for the development of the digital economy and society for 2018-2020 and approval of the plan of measures for its implementation, Decree of the Cabinet of Ministers of Ukraine No. 67-p of 17.01.2018, 2018. URL: http://surl.li/spoqhp.

[5] On the approval of the State Strategy for Regional Development for 2021–2027. decree of the cabinet of ministers of ukraine no. 695 of 05.08.2020, 2020. URL: http://surl.li/klrbuv.

[6] OECD, OECD Handbook for Internationally Comparative Education Statistics (2018) 148. doi:doi.org/10.1787/9789264304444-en.

[7] OECD, Country Digital Education Ecosystems and Governance, 2023. URL: https://www.oecd-ilibrary.org/content/publication/906134d4-en. doi:10.1787/906134d4-en.

[8] OCDE, Education Policy in Japan, 2018. URL: https://www.oecd-ilibrary.org/content/publication/9789264302402-en. doi:10.1787/9789264302402-en.

[9] V. H. Sarioglo, Big Data as a Source of Information and a Toolkit for Official Statistics: potential, Problems, Prospects, Statistics of Ukraine 4 (2016) 12–19. URL: https://su-journal.com.ua/index.php/journal/article/view/157.

[10] O. M. Khmelevska, Tutoring as a component of the shadow education and approaches to its Assessment in Ukraine, Demography and social economy 1 (2017) 37–53. doi:10.15407/dse2017.01.037.

[11] C. Bo, P. W. Yuen, A Composite Index of Economic Integration in the Asia-Pacific Region, Asia Pacific Foundation of Canada, 2008. URL: https://www.asiapacific.ca/sites/default/files/filefield/PECCIntegrationIndex.pdf.

[12] I. P. Vorotnykova, N. V. Morze, L. M. Hrynevych, Digital transformation of secondary education of Ukraine and the quality of teaching natural and mathematical sciences in the conditions of war, CEUR Workshop Proceedings 3553 (2023) 57–74. URL: https://ceur-ws.org/Vol-3553/.

[13] T. S. Eng, The impact of ict on learning: a review of research., International Education Journal 6 (2005) 635–650. URL: https://files.eric.ed.gov/fulltext/EJ855017.pdf.

[14] M. Brown, G. Conole, M. Beblavỳ, Education outcomes enhanced by the use of digital technology – Reimagining the school learning ecology, European Commission and Directorate-General for Education, Youth, Sport and Culture Publications Office, 2019. URL: https://eenee.eu/wp-content/uploads/2021/05/EENEE_AR38-1.pdf.

[15] R. Wood, J. Ashfield, The use of the interactive whiteboard for creative teaching and learning in literacy and mathematics: a case study, British Journal of Educational Technology 39 (2008) 84 – 96. doi:10.1111/j.1467-8535.2007.00699.x.

[16] E. A. Hanushek, Some Findings From an Independent Investigation of the Tennessee STAR Experiment and From Other Investigations of Class Size Effects, Educational Evaluation and Policy Analysis 21 (1999) 143–163. doi:10.3102/01623737021002143.

[17] E. A. Hanushek, The economic value of higher teacher quality, Economics of Education Review 30 (2011) 466–479. URL: https://www.sciencedirect.com/science/article/pii/S0272775710001718. doi:10.1016/j.econedurev.2010.12.006.

[18] A. B. Krueger, D. M. Whitmore, The Effect of Attending a Small Class in the Early Grades on College-Test Taking and Middle School Test Results: Evidence from Project STAR, The Economic Journal 111 (2001) 1–28. URL: http://www.jstor.org/stable/2667840.

[19] L. Wang, L. Calvano, Class size, student behaviors and educational outcomes, Organization Management Journal 19 (2022) 126–142. URL: https://www.emerald.com/insight/content/doi/10.1108/OMJ-01-2021-1139/full/html. doi:10.1108/OMJ-01-2021-1139.

[20] R. J. Rodriguez, B. Elbaum, The Role of Student–Teacher Ratio in Parents' Perceptions of Schools' Engagement Efforts, The Journal of Educational Research 107 (2014) 69–80. doi:10.1080/00220671.2012.753856.

[21] A. Gupta, A 'shadow education' timescape: An empirical investigation of the temporal arrangements of private tutoring vis-à-vis formal schooling in India, British Journal of Educational Studies 70 (2022) 771–787. doi:10.1080/00071005.2021.2024137.

[22] Y. Ma, W. Jia, J. Wang, X. Wang, Y. Zhou, Z. Yan, Does education finance reduce the inequality of educational results? The mediation effect of shadow education, Frontiers in Psychology 13 (2022). URL: https://www.frontiersin.org/journals/psychology/articles/10.3389/fpsyg.2022.1041615/full.

[23] D. Ansong, I. Koomson, M. Okumu, M. Alhassan, T. Makubuya, M. K. Abreh, Private supplementary tutoring expenditures and children's learning outcomes: Gender and locational evidence from Ghana, Studies in Educational Evaluation 76 (2023) 101232. doi:10.1016/j.stueduc.2022.101232.

[24] General secondary and post-secondary non-tertiary education in Ukraine in 2019, 2020 and 2021 school years. Statistical information, 2021. URL: https://ukrstat.gov.ua/operativ/operativ2005/osv_rik/osv_u/zag_ser_prof_osv/arch_zag_ser_prof_osv.htm.

[25] General secondary education in Ukraine in 2022 school year. Statistical information, 2022. URL: https://ukrstat.gov.ua/operativ/operativ2022/osv/osv_rik/zso21_ue.xlsx.

[26] Information about the material base and the use of modern information technologies in day institutions of general secondary education of the Ministry of Education and Science, other ministries and departments, and private institutions. Newsletter., 2020. URL: https://iea.gov.ua/wp-content/uploads/2020/03/mat.baza_19-20.pdf.

[27] Information about the material base and the use of modern information technologies in day institutions of general secondary education (except specialized institutions) of the Ministry of Education and Science, other ministries and departments, and private institutions. Newsletter., 2022. URL: https://iea.gov.ua/wp-content/uploads/2022/04/byuleten-materialna-baza-2021-2022-1.xlsx.
[28] National commission for the state regulation of electronic communications, radio frequency spectrum and the provision of postal services for 2019-2022, 2019-2022. URL: http://surl.li/djqifq.
[29] Google trends, 2022. URL: https://www.google.com/trends/.
[30] K. Jajuga, M. Walesiak, Standardisation of Data Set under Different Measurement Scales, in: R. Decker, W. Gaul (Eds.), Classification and Information Processing at the Turn of the Millennium, Springer Berlin Heidelberg, Berlin, Heidelberg, 2000, pp. 105–112. doi:10.1007/978-3-642-57280-7_11.
[31] R. Gunst, J. Webster, Regression analysis and problems of multicollinearity, Communications in Statistics 4 (1975) 277–292. doi:10.1080/03610927308827246.
[32] V. Y. Bykov, O. V. Ovcharuk, I. V. Ivaniuk, O. P. Pinchuk, V. O. Galperina, The current state of the use of digital tools for organization of distance learning in general secondary education institutions: 2022 results, Information Technologies and Learning Tools 90 (2022) 1–18. URL: https://journal.iitta.gov.ua/index.php/itlt/article/view/5036. doi:10.33407/itlt.v90i4.5036.