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Assessing the students' digitalisation at country level by building a composite index based on PISA 2018

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Abstract: This paper contributes to measuring information and communication technologies' (ICT) adoption by students and compares it among different countries. A composite index named the students digitalisation index (SDI) is built based on the 2018 PISA database and by applying multivariate statistical techniques. The index assesses ICT adoption beyond equipment acquisition (ICT access) and activities performed by using ICT (ICT use), and includes students' perception of their digital skills and competencies (ICT engagement). A digital gap between countries was detected. Statistically significant mean differences are observed in terms of type of country, household income, gender, grade repetition, and parents' highest education. There are no other composite indexes to compare students' digitalisation among countries. The SDI index is useful to explain the consequences of mass quarantine due to COVID-19 in the educational field. Countries with a low SDI are expected to suffer more as they are less prepared for virtual education.

Keywords: digital gap; students' digitalisation; education; ICT adoption; PISA; composite index.

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1 Introduction

The ICT role on education has evolved from the relevance of ICT access, to examining the ICT type of use and more recently, the perception about the students' ICT autonomy and competences (OECD, 2016). The relevance of these ICT components has become evident with the consequences of the pandemic. Education has been roughly decentralised into students' own homes and homeschooling has become a new practice of education mediated by technology tools (Williamson et al., 2020). Moreover, many parents across countries indicated homeschooling to be a negative experience and differences between countries were generally small (Thorell et al., 2021). In this scenario, students from less developed countries are expected to be less prepared to engage in online education. This disadvantage position is not only explained by their weak ICT access. Their skills or abilities to use ICT are also critical to connect the virtual world; and children without those skills will be in a worse position. What will happen with the education of children whose parents work outside home during the pandemic? What will happen with children without their parents at home and not interested in ICT? Which countries will be digitally ready to confront with the consequences of quarantines?. Efforts to measure the level of ICT adoption, as an aggregate concept of ICT among students, has been done by many international organisms. For instance, PISA has included the ICT questionnaire since 2000 and has built some ICT indexes about this subject such as the ICT resources at home, ICT resources at school, among others. However, the different dimensions related to ICT adoption in education are not yet simultaneously considered.

To measure the digital gap among students at the country level, both first-level and second-level gaps should be examined. Most data on ICT adoption refers to availability of equipment and devices (PC, internet). However, ICT access is a necessary but not sufficient condition to improve education (DiMaggio and Hargittai, 2001). Other concerns such as type of ICT uses, whether students use ICT for learning or schooling or just for leisure, are also relevant. Besides, the digital skills inherent to each student determine their readiness and competences to properly exploit ICT.

Moreover, inequality of ICT at student level must include other dimension which is the ICT engagement. In this vein, we could refer to a third-level digital gap in terms of inequalities of ICT engagement, that is, to mainly engage in the ICT usage. This dimension considers digital readiness and familiarity with ICT, which depends on motivational factors (either external i.e., family or internal, i.e., individual abilities) (Juhaňák et al., 2019).

Recent literature has recognised the critical role of these three components to explain the digital gap in education (Chaudron et al., 2018; Hatlevik et al., 2018, 2015; Ryan and Deci, 2017). However, there is a lack of a multidimensional international index and of studies that explain the digital gap in education by comparing among countries. Which are the best and worst positioned countries in terms of students' digitalisation? Is a proper ICT access a sufficient condition for a country to be included in the top of the ranking? Although there is no consensus on the benefits of composite indexes, we consider they are useful in the educational field to capture attention of more disadvantaged countries (and therefore students) and policy makers; especially in times of the pandemic crisis. We considered a composite index to be useful to communicate and represent several trends and dimensions (Araujo and Pinto da Rocha, 2009). This composite information could be suitable for stakeholders and decision makers. Moreover, the controversy in the empirical evidence towards the ICT educational outcomes as well as the recent context stricken with the pandemic crisis, encourage the study of ICT on education. Some evidence shows COVID-19 has increased the digital divide among the students (Mohd Aba Sha'ar et al., 2023; Guo and Wan, 2022).

The objective of this paper is building a composite index based on information about ICT adoption among students around the world. To achieve this goal, we use PISA 2018 database for the whole students' sample. By employing multivariate analysis technique, we built the students digitalisation index (SDI). The idea is to remark different and complementary sides of ICT adoption in education in order to describe and compare among countries.

The paper is structured as followed. First of all, a literature revision on the ICT incidence on education and ICT effect on the educational performance is presented. Then, we explain the relevant factors for a better comprehension of the digital gap in education. Moreover, we describe the state of the art on ICT indicators on education for international comparison. Next, we built a composite index named SDI based on PISA database. Later on, a comparison of SDI means is performed based on different independent variables such as type of country, gender, parent's education, household income and grade repetition. We also compare the SDI with other international indexes to examine correlation between them. Lastly, final remarks are shared to discuss the advantages and disadvantages of the index.

2 Theoretical framework

This section begins with a conceptual framework that provides the baselines for the selection of the indicators that will be part in the compound index. Due to the multiplicity of aspects related to ICT adoption at student level, using simple indicators or variables (i.e., internet availability or not, ICT use at school or not) turns the analysis incomplete.

In the contemporary society, internet access is considered one of the basic human rights because of its significance for the development of plenty of human activities (United Nations, 2016). Nevertheless, inequality of internet access has become a critical barrier to recognising the true impact of IT especially in developing countries (Bradshaw et al., 2005). In regions such as Latin America, the digital exclusion is only one of many types of exclusions. These environments of high inequality are always steps backwards in terms of ICT access and use compared to more developed and equalitarian regions (Ullah, 2020; Alderete, 2019; Barrantes Cáceres and Vargas, 2016; Robinson et al., 2015; Stewart, 2003).

While ICT access relates to technology availability, ICT use responds to how and for what purposes (Van Deursen and Van Dijk, 2009). Although there is quite consensus about the difference between the concepts of ICT access and ICT use, measuring the digital divide is not a straightforward issue. The digital divide usually refers to disparity in ICT access and/or ICT use at the household or country levels. Therefore, at first place, we can distinguish two digital gaps. The first-level digital gap, that represents the divide between individuals with and without internet access (NTIA, 1990), and the second-level digital gap that focuses on the inequities of internet use. This second gap arises once people gain access to internet and it is linked to inequalities in the capacity to properly exploit ICT (Robinson et al., 2003; Hargittai, 2003). In this vein, Chen and Wellman (2003) had assumed "There is no one digital divide; there are many divides. Indeed, it is more accurate to use the plural – digital divide*s* – because the digital divide is multifaceted and varies within and between countries, both developed and developing" (2003, p.2).

In the education research field, ICT are considered a critical tool to enhance educational outcomes. However, although there is plenty of research on the ICT effect on the educational performance, there is still no consensus. Differences arises in terms of the ICT variable employed (whether it is ICT access or ICT use), the place of ICT availability (at home or at school), the data employed (PISA, TIMMS), among others.

During the last decade, many studies have found a positive effect of ICT on education (González-Betancor et al., 2021; Fernández-Gutiérrez et al., 2020; Formichella and Di Meglio, 2020; Gómez Fernández and Mediavilla, 2018; Mediavilla and Escardíbul, 2015; Botello and Rincón, 2014; Trucco and Espejo, 2013; Cabras and Tena, 2013; Cristia et al., 2012; Tansini and Aguilar, 2011; Jewitt and Parashart, 2011). On the other side, other studies have achieved a negative or even null impact of ICT on the educational performance (Mora et al., 2018; Santín and Sicilia, 2014; Witte and Rogge, 2014; Muñoz and Ortega, 2014; De Melo et al., 2013; Cordero et al., 2012; Malamud and Pop-Eeches, 2010).

ICT use, which is one of the dimensions of ICT adoption, can take place in several environments and contexts, either in school or out of school. Some recent authors suggest that students utilise modern technology more frequently at home than at school (Scherer and Hatlevik, 2017; Wastiau et al., 2013). On the other hand, certain evidence shows that the positive ICT effects at school (either access or use) on the educational performance could be dissipated or even become negative if ICT access at home were not present (Alderete et al., 2017; Mediavilla and Escardíbul, 2015; Angrist and Lavy, 2002). A possible explanation is that ICT at school without proper educational policies (resources, strategies) to attend the initial digital inequalities coming from home, could deepen the gap between students (Alderete et al., 2017). These digital inequalities are mainly related to digital skills and abilities.

In fact, one of the critical issues of contemporary society is the development of digital literacy and skills (Erstad, 2011; Tsitouridou and Vryzas, 2011; Sefton-Green et al., 2009; Lankshear and Knobel, 2008). Most literature states that digital literacy can be developed as an informal learning process in the home, out of school and among peers (Arnseth et al., 2016; Erstad, 2012), beyond the formal learning process at school. In this respect, some evidence argues leisure book reading explains the variance in PISA Reading scores in Finland (Torppa et al., 2018).

More importantly, the family background is significantly attached to the students' digital competence (Hatlevik et al., 2018, 2015; Fraillon et al., 2014). ICT access at home together with the family background on digital language and experience has been shown to be relevant factors for students' digitalisation (Buckingham, 2006). In fact, Chaudron et al. (2018) argue that students use the technology as self-explorers and self-learners regardless of their parents many ways to perform the ICT-related activities. In this vein, PISA incorporates this approach on the 'ICT familiarity questionnaire' in the PISA 2015 (OECD, 2017a, 2017b; Kuger et al., 2016). By perceived ICT competence it denotes students' tendency to connect digital technology with the skill or ability to use the technologies. It resembles a form of evaluation of our own ICT-related skills and knowledge, and it is also the basis of many studies (Christoph et al., 2015; Goldhammer et al., 2016; Zylka et al., 2015; Aesaert et al., 2015; Litt, 2013). On the other side, perceived ICT autonomy shows the perception of control of an individual in terms of ICT use and independency in ICT-related activities (Goldhammer et al., 2016) in respect with his objectives and interests.

A large body of research reviewed (Ryan and Deci, 2017; Wehmeyer et al., 2017; Liu and Wang, 2016) has demonstrated that digital literacies or skills are positively associated with the terms ICT autonomy and competence (Calvani et al., 2012; Erstad, 2008). Moreover, ICT use has been found to be positively related to ICT competence (Hatlevik et al., 2015). This result can have a significant impact not only on the development of students' ICT competence, but also on their autonomy in ICT use. In this respect, Juhaňák et al. (2019) offers a review of the literature on the ICT interest, competence and autonomy motivational factors. The authors examine the relationship between the perceived competence and autonomy in ICT use at the age of fifteen and the ICT use at home (both for leisure time activities and for school purposes) and student interest in ICT, among others. Based on the results, ICT competence and autonomy are mostly due to out-of-school factors.

Furthermore, a strong positive correlation with ICT use is expected if there is interest in ICT. Chen and Hu (2020) obtain a positive relationship between adolescents' interest in ICT and their ICT self-efficacy or competence. On the other side, since ICT interest is a strong motivational factor to achieve a higher degree of participation and higher quality of the learning process (Ryan and Deci, 2000), students are more prone to develop ICT competence and autonomy (Christoph et al., 2015).

Therefore, ICT interest, ICT competence and autonomy are strongly interrelated. ICT competence and ICT autonomy are certainly connected to the skills and abilities of digital technology use (Juhaňák et al., 2019). In this respect, Meng et al. (2019) argues that the ICT engagement concept is a wider term that involves ICT competence, autonomy and interest. The concept was originally defined by Zylka et al. (2015) and later on used by PISA. Zylka et al. (2015) provide the theoretical basis of ICT engagement based on the motivation and meta-cognition factors. The authors validated an ICT engagement model that had five dimensions: Positive ICT self-concept, negative ICT self-concept, social exposure to ICT, interest in computers and interest in mobile devices. This ICT engagement model was used in the PISA 2015 survey. However, the PISA 2015 ICT engagement model embraced only four dimensions: ICT interest, perceived ICT competence, perceived autonomy of ICT use, and ICT in social interaction.

Lastly, Meng et al. (2019) argues ICT engagement as a multidimensional construct has been examined as an explanatory factor of students' achievement. However, since researchers have used single or individual aspects or dimensions of the term, they have obtained mixed results (Skryabin et al., 2015; Cheema and Zhang, 2013; Lee and Wu, 2012). While the first two papers find a positive effect, the other two obtain a negative one. See Odell et al. (2020) for an extensive revision of the soft predictors of educational outcomes.

3 Methodology

A composite index is built based on simple indicators or variables that are selected on behalf of the theoretical models described in the previous section. The index should measure multidimensional factors that cannot be considered under a single indicator (OCDE, 2008). On the other side, this composite index takes as a methodological framework the ICT development index (IDI) from the International Telecommunication Union (ITU). The IDI has been annually published between 2009 and 2017 to stablish a benchmark framework of the ICT development at country level. The IDI compares among countries and different time periods. The last published version of IDI is based on three weighted sub- indexes: Access, Use and ICT skills (ITU, 2017). Nowadays, the IDI is under methodological revision and therefore, it is not been published since 2017 (ITU, 2019). This study, on the contrary, takes the 15-year old students in each country tested by PISA as the unit of analysis.

By using the factorial analysis technique, we can identify a relatively small number of factors from a set of interrelated variables. This analysis provides information to group the set of variables into a small number of feasible factors with a clear meaning and precise sense. Principal Components Analysis (PCA) is a multivariate statistics technique which is mainly descriptive. The method entails a linear combination of all the original indicators so that the first principal component is a combination that explains most of the sample variance. The second component explains the second largest percentage of the cumulative variance, and so on. Besides, the first component is uncorrelated with the second component, and so forth. Some requirements to apply the PCA technique are:

a continuity of variables

b the number of individuals or cases must be larger than the number of original variables.

Based on PISA 2018 database, especially from the ICT familiarity questionnaire, we proceed to search for indicators of ICT adoption. PISA offers information about the following variables:

1 ICTHOME: is an index that represents the availability of ICT at home and if students used it for various purposes.

2 ICTSCH: is an index about the availability of ICT at school.

3 ENTUSE (leisure activities): is an index about how often digital devices are used outside of school for leisure activities.

4 HOMESCH (for school work outside of school): is an index about how often digital devices are used outside of school for school work outside of school.

5 USESCH (use of ICT at school): is an index about how often digital devices are used at school.

6 INTICT: is and index of students' ICT interest.

7 COMPICT: is an index of the perceived competence in ICT usage.

8 AUTICT: is an index of the perceived autonomy related to ICT usage.

9 ICTCLASS: s an index of the related use of digital devices during classroom lessons.

10 ICTOUTSIDE: is an index of the subject-related use of digital devices outside of classroom lessons.

11 SOIAICT: is an index of the degree to which ICT is a part of their daily social life.

12 ICTRES: this index is based on the student questionnaire. Students reported on the availability of 16 household items at their home. PISA built an index on the availability of digital devices at home (computer, tablet, e-book, cell phones)

Based on these indexes, we decide to build a multidimensional index, a latent variable of student digitalisation, instead of using PISA's ICT indexes separately. The idea is to remark different and complementary sides of ICT adoption in education: the role of access (captured by the availability of ICT resources, devices, connectivity), the role of usage (with the different uses of ICT inside and outside school), and the role of engagement (related to digital skills and competences).

4 Results

4.1 Building the SDI

By means of PISA's ICT individual variables, we build a set of factors or indicators through factorial analysis. To test the adequacy of the factorial analysis we observe the Kaiser-Meyer-Olkin (KMO) measure and the Barlett test. KMO is a Measure of Sampling Adequacy that takes values between 0 and 1, and values nearby 1 are better. A minimum threshold for KMO is 0.6. In this case, the measure is 0.716; then we consider the factorial analysis to be adequate. On the other side, the Bartlett's test of sphericity tests the null hypothesis that the correlation matrix is an identity matrix. Results from Table 1 show we can reject this null hypothesis. Then we consider the Factorial Analysis to be useful with the data.

Table 1 KMO and Bartlett test

Kaiser-Meyer-Olkin measure of sampling adequacy		0.716
Bartlett's test of sphericity	Approx. chi-square	67,6730.103
	Df	45
	Sig.	0.000

Source: Own elaboration

Table 2 Communalities (first step)

	Variables	*Initial*	*Extraction*
1	ICT as a topic in social interaction (SOIAICT)	1.000	0.564
2	Perceived autonomy related to ICT use AUTICT	1.000	0.663
3	Perceived ICT competence COMPICT	1.000	0.670
4	Subject-related ICT use during lessons ICTCLASS	1.000	0.453
5	Subject-related ICT use outside of lessons ICTOUTSIDE	1.000	0.495
6	Use of ICT at school in general USESCH	1.000	0.612
7	Use of ICT outside of school (for school work activities) HOMESCH	1.000	0.587
8	ICT use outside of school (leisure) ENTUSE	1.000	0.414
9	Interest in ICT INTICT	1.000	0.539
10	ICT available at home ICTHOME	1.000	0.778
11	ICT available at school ICTSCH	1.000	0.434
12	ICT resources ICTRES	1.000	0.735

Note: Extraction method: principal components analysis

Source: Own elaboration based on PISA 2018

Table 2 shows the initial variables included to build the index. Since variables ICTSCH and ENTUSE have communalities lower than 0.5 (we approximate values higher than 0.45 by 0.5), we excluded them from the analysis. Values lower than 0.5 indicate that these variables can be extracted to describe the components as shown in Table 2.

In a second step, once we exclude the non-significant variables for FA, we obtain communalities in Table 3. In this case, all variables are higher than 0.5. The common factor variances of the ten variables are all greater than 0.5 which indicates that these variables can be extracted to describe the components as shown in Table 4.

Table 3 Communalities (second step)

		Initial	*Extraction*
1	Perceived autonomy related to ICT use	1 000	0 687
2	Perceived ICT competence	1 000	0 706
3	Subject-related ICT use during lessons	1 000	0 489
4	Subject-related ICT use outside of lessons	1 000	0 542
5	Use of ICT at school in general	1 000	0 606
6	Use of ICT outside of school (for school work activities)	1 000	0 552
7	Interest in ICT	1 000	0 541
8	ICT available at home	1 000	0 785
9	ICT resources	1 000	0 811
10	ICT as a topic in social interaction	1 000	0 596

Note: Extraction method: principal components analysis

Source: Own elaboration based on PISA 2018

When applying the principal components analysis, we obtain the results in Table 4. This table comprises the eigenvalue values for each factor, the proportion of variance explained by each extracted factor and the proportion of cumulative variance explained by all extracted factors.

For component 1, the eigenvalue is 3,231; for component 2 is 1,696; and for component 3 is 1,389. Therefore, we explain the 10 ICT variables by means of three fictitious variables explaining 63,15% of total variance through the PCA technique.

Table 5 contains the component loadings of each variable over each of the components obtained through the CPA. The ten variables can be explained by means of three fictitious variables, which are explained by the bold variables. We interpret these latent factors as:

- Component 1: ICT engagement.
- Component 2: ICT use.
- Component 3: ICT access.

Therefore, the SDI can be expressed as a linear combination of these three extracted components. Since these components have divergent values, from positive to negative ones, their linear combination has also divergent values. Then, we normalise the result to obtain a scalar from 0 to 1, using the following formulae:

$$\begin{aligned} SDI = {} & CP1 * (\%CP1 \text{ variance}/\%\text{cumulative variance}) \\ & + CP2K * (\%CP2 \text{ variance}/ \% \text{ cumulative variance}) \\ & + CP3 * (\% \text{ CP3 variance}/\% \text{ cumulative variance}) \end{aligned} \tag{1}$$

where CPI means component i; i = 1, 2 or 3.

$$SDI = 0.41 * \text{Engagement} + 0.33 * \text{Use} + 0.26 * \text{Access} \tag{2}$$

Table 4 Total variance explained

Component	*Initial eigenvalues*			*Extraction sums of squared loadings*			*Rotation sums of squared loadings*		
	Total	*% of total variance*	*Cumulative %*	*Total*	*% of total variance*	*Cumulative %*	*Total*	*% of total variance*	*Cumulative %*
1	3.231	32,309	32,309	3.231	32,309	32,309	2.595	25,949	25,949
2	1.696	16,959	49,268	1.696	16,959	49,268	2.097	20,974	46,923
3	1.389	13,886	63,154	1.389	13,886	63,154	1.623	16,231	63,154
4	0.869	8,692	71,846						
5	0.618	6,180	78,026						
6	0.595	5,950	83,976						
7	0.470	4,701	88,677						
8	0.401	4,012	92,689						
9	0.370	3,699	96,388						
10	0.361	3,612	100,000						

Note: extraction method: components principal analysis

Source: Own elaboration

Table 5 Rotated matrix

		Component		
		1	*2*	*3*
1	Perceived autonomy related to ICT use	**0.820**	0.008	0.119
2	Perceived ICT competence	**0.823**	0.126	0.112
3	Subject-related ICT use during lessons	–0.067	**0.680**	0.147
4	Subject-related ICT use outside of lessons	0.021	**0.734**	0.056
5	Use of ICT at school in general	0.214	**0.745**	0.069
6	Use of ICT outside of school (for school work activities)	0.312	**0.674**	0.015
7	Interest in ICT	0.728	0.064	0.085
8	ICT available at home	0.077	0.126	**0.873**
9	ICT resources	0.098	0.100	**0.889**
10	ICT as a topic in social interaction	**0.742**	0.200	–0.074

Notes: Extraction method: components principal analysis. Rotation method: varimax with kaiser normalisation.
Rotation has converged in 5 iterations.

Source: Own elaboration

4.2 Exploratory analysis

In this section we pretend to determine the average SDI and average subcomponents by country, to analyse the best and worst positioned countries. Besides, we provide information about the human development index (HDI) category of each country, from medium (M) to high (H) and very high (VH).

Table 6 Average SDI by country

	Country	*HDI*	*Mean*	*N*	*Standard dev*
1	Denmark	VH	0.5861	42396	0.08999
2	Australia	VH	0.5645	171152	0.10198
3	Sweden	VH	0.5603	69114	0.10323
4	New Zealand	VH	0.5433	40226	0.09912
5	USA	VH	0.5371	2999760	0.10574
6	UK	VH	0.5350	400741	0.09503
7	Iceland	VH	0.5314	2678	0.10266
8	Malta	VH	0.5304	2836	0.09902
9	Moscow Region (RUS)	VH	0.5219	53305	0.11405
10	Singapore	VH	0.5151	41282	0.10103
11	Tatarstan (RUS)	VH	0.5148	27074	0.10519
12	France	VH	0.5133	563438	0.09900
13	Poland	VH	0.5125	264125	0.09643
14	Spain	VH	0.5121	270879	0.09583

Source: Own elaboration based on PISA

Table 6 Average SDI by country (continued)

	Country	*HDI*	*Mean*	*N*	*Standard dev*
15	Lithuania	VH	0.5116	18907	0.10834
16	Russian Federation	VH	0.5115	999999	0.11163
17	Italy	VH	0.5056	363189	0.09509
18	Finland	VH	0.5049	44535	0.09217
19	Bulgaria	VH	0.5020	26295	0.12115
20	Latvia	VH	0.5006	13074	0.09268
21	Luxembourg	VH	0.4991	4378	0.10341
22	Belgium	VH	0.4988	81657	0.09099
23	Israel	VH	0.4981	70001	0.11238
24	Kazakhstan	VH	0.4975	161259	0.10766
25	Estonia	VH	0.4974	10021	0.09220
26	Ireland	VH	0.4946	45691	0.09282
27	Macao	VH	0.4932	3670	0.08915
28	Switzerland	VH	0.4927	54108	0.09697
29	Brunei Darussalam	VH	0.4900	4900	0.09349
30	Croatia	VH	0.4889	28913	0.10764
31	Chile	VH	0.4889	135660	0.11088
32	Hong Kong	VH	0.4869	45277	0.09830
33	Thailand	H	0.4864	513856	0.10642
34	Slovak Republic	VH	0.4863	32529	0.09855
35	Hungary	VH	0.4855	71141	0.10229
36	Slovenia	VH	0.4848	13267	0.09756
37	Uruguay	VH	0.4835	18556	0.10864
38	Greece	VH	0.4831	74531	0.10411
39	Serbia	VH	0.4811	36223	0.11553
40	Albania	H	0.4796	24301	0.12207
41	Costa Rica	VH	0.4744	35859	0.12229
42	Czech Republic	VH	0.4736	65064	0.09762
43	Panama	VH	0.4705	13079	0.12201
44	Mexico	H	0.4646	849664	0.12040
45	Chinese Taipei	H	0.4646	212545	0.10325
46	Brazil	H	0.4629	1024400	0.12019
47	Turkey	VH	0.4568	786693	0.12009
48	Dominican Republic	H	0.4494	73300	0.13389
49	South Korea	VH	0.4471	426718	0.10453
50	Georgia	VH	0.4414	20627	0.11251
51	Morocco	M	0.4268	176981	0.12350
52	Japan	VH	0.3812	1020698	0.10389
	Total		0.4910	12550573	0.11764

Source: Own elaboration based on PISA

The fifth best-positioned countries are Denmark, Australia, Sweden, New Zealand and USA. On the other side, Chile is the Latin American best-positioned country in the ranking, with a SDI of 0.4889 slightly below the average SDI worldwide of 0.4910. All Latin American countries are below the worldwide average. Moreover, most of countries included by PISA are from a very high HDI, except for a few cases. Countries at the bottom of SDI correspond to the categories High and Medium in the HDI. The average SDI for very high HDI countries is higher (0.5048) than for high (0.4817) or medium (0.4564) HDI countries; and these differences are statistically significant.

Table 7 summarises the descriptive statistics of the overall SDI and subcomponents. We observe that the ICT access subcomponent has an average value (0.5532) higher than the ICT engagement (0.5335) and ICT use (0.4067) subcomponents, respectively.

Table 7 Descriptive statistics of SDI and subcomponents

	N	*Min*	*Max*	*Mean*	*St. dev.*
Engagement	12550573	0.00	1.00	0.5335	0.13633
Use	12550573	0.00	1.00	0.4067	0.14002
Access	12550573	0.00	1.00	0.5532	0.13513
SDI	12550573	0.00	1.00	0.4910	0.11764

Source: Own elaboration based on PISA 2018

4.3 Analysis of SDI subcomponents

In this section, we share the subcomponents' values obtained for each country for a better interpretation of the overall SDI. Table 8 lists the subcomponents values by country.

Table 8 Average SDI subcomponents by country

Country	*Engagement*	*Use*	*Access*
Albania	0.5482	0.4136	0.4923
Australia	0.5373	0.4773	0.6515
Belgium	0.5395	0.3506	0.6328
Brazil	0.5680	0.3727	0.4682
Brunei Darussalam	0.5506	0.3616	0.5792
Bulgaria	0.5099	0.4495	0.5664
Chile	0.5465	0.4112	0.5222
Chinese Taipei	0.5584	0.3220	0.5497
Costa Rica	0.5522	0.4178	0.4676
Croatia	0.5646	0.3630	0.5529
Czech Republic	0.5107	0.3731	0.5850
Denmark	0.5160	0.5390	0.6651
Dominican Republic	0.5586	0.3931	0.4229
Estonia	0.5260	0.3994	0.5906
Finland	0.5385	0.3830	0.6107

Source: Own elaboration based on PISA 2018

Table 8 Average SDI subcomponents by country (continued)

Country	*Engagement*	*Use*	*Access*
France	0.5773	0.3636	0.5955
Georgia	0.5088	0.3694	0.5089
Greece	0.5518	0.3558	0.5667
Hong Kong	0.5619	0.3599	0.5557
Hungary	0.5354	0.3739	0.5763
Iceland	0.5339	0.4253	0.6347
Ireland	0.5613	0.3171	0.6290
Israel	0.5328	0.3739	0.6130
Italy	0.5270	0.4120	0.5950
Japan	0.4741	0.2354	0.5714
Kazakhstan	0.5188	0.4779	0.5059
South Korea	0.5011	0.3484	0.5617
Latvia	0.5274	0.4248	0.5656
Lithuania	0.5433	0.4244	0.5697
Luxembourg	0.5349	0.3548	0.6358
Macao	0.5501	0.3853	0.5594
Malta	0.5801	0.3604	0.6393
Mexico	0.5403	0.4278	0.4484
Morocco	0.5387	0.3728	0.4201
Moscow Region (RUS)	0.5237	0.4596	0.5841
New Zealand	0.5371	0.4591	0.6192
Panama	0.5615	0.4019	0.4623
Poland	0.5330	0.4144	0.6005
Russian Federation	0.5237	0.4593	0.5574
Serbia	0.5387	0.3792	0.5531
Singapore	0.5718	0.3837	0.5843
Slovak Republic	0.4955	0.4154	0.5898
Slovenia	0.5281	0.3712	0.5892
Spain	0.5597	0.3716	0.6102
Sweden	0.5406	0.4768	0.6361
Switzerland	0.5369	0.3472	0.6252
Tatarstan (RUS)	0.5157	0.4836	0.5488
Thailand	0.5396	0.4965	0.4220
Turkey	0.5264	0.4182	0.4618
UK	0.5569	0.3989	0.6404
USA	0.5318	0.4580	0.6126
Uruguay	0.5393	0.4239	0.5037
Total	0.5335	0.4067	0.5532

Source: Own elaboration based on PISA 2018

Table 9 synthetises information obtained. The best positioned countries in terms of SDI are Denmark, Australia, Sweden, New Zealand and USA. Denmark best position is mainly explained by its best position in ICT access and Use. However, the country loses position in terms of engagement. Brazil is the only Latin American country among the top of the ranking in respect to ICT engagement.

Table 9 Best and worst positioned countries by subcomponent and SDI

	ICT access	*ICT use*	*ICT engagement*	*SDI*
Best positioned	Denmark	Denmark	Malta	Denmark
	Australia	Thailand	France	Australia
	UK	Tatarstan (RUS)	Singapore	Sweden
	Malta	Kazakhstan	Brazil	New Zealand
	Sweden	Australia	Croatia	USA
Worst positioned	Turkey	South Korea	Bulgaria	Dominican Republic
	Mexico	Switzerland	Georgia	South Korea
	Dominican Republic	Chinese Taipei	South Korea	Georgia
	Thailand	Ireland	Slovak Republic	Morocco
	Morocco	Japan	Japan	Japan

Source: Own elaboration

On the other side, the worst positioned countries in terms of SDI are Dominic Republic, South Korea, Georgia, Morocco and Japan. Mexico locates among the worst Latin-American countries in ICT access. Moreover, Japan's worst place is explained by its weak position in terms of ICT use and engagement. Japan's SDI ranking differs with other international indexes on ICT development, such as IDI. The IDI 2017 ranking for Japan is much better than SDI; Japan is placed among the tenth best IDI positioned countries. South Korea is also in a weak position either because of the ICT use and the ICT engagement. This result confirms Kim et al.'s (2020) findings about the weak digital literacy education in South Korea compared to other OECD countries. This contemporary scene is opposed to the mid-90s, when the Korean government set about strategic planning to position South Korea among the best knowledge societies (OECD, 2014). Based on this information, we can expect the consequences of the quarantine due to covid will be worse for students and parents from these countries. There are recent articles that explain the disparities caused by covid in the educational system of these countries [Iwabuchi et al., (2022) for Japan; Tinmaz and Öztürk (2020) for South Korea; Mounjid et al. (2021) for Morocco].

4.4 Sensitivity analysis

The SDI was found to be robust in respect to applying different methodologies of weighting, such as:

1 equal weighting of the subcomponents

2 assign weights equal to the inverse of the standard deviation of the subcomponents

3 without weighting of the subcomponents.

When we apply any of the methodologies listed, we obtain the same ranking for the best and worst positioned countries. In the middle, there are just marginal changes on countries rankings[1]. In respect to the worst positioned countries, South Korea is better positioned with these methodologies than with the original one (Table 8) and, therefore, Turkey becomes worse and is included in the set of worst positioned countries.

To sum up, changes in methodology do not alter the ranking of the best positioned countries, and there are just marginal changes in the rest of the countries. Table 10 brings information about the descriptive statistics of the alternative methodologies.

Table 10 Descriptive Statistics of SDI with different methodology

Types of indexes		*N*	*Min*	*Max*	*Mean*	*St. dev.*
1	SDI_equal_weighting	12550573	0.16	0.84	0.4928	0.07841
2	SDI_inverse_weighting	12550573	3.52	18.50	10.9086	1.73146
3	SDI_without_weighting	12550573	0.48	2.54	1.4935	0.23759

Source: Own elaboration

4.5 Correlation between IDI, NRI and SDI

We can compared the SDI with other international indexes at country level related to the ICT topic, such as the ICT development index (IDI) and the network readiness index (NRI).

The IDI is a composite index about the access and use of ICTs for households and individuals (while SDI is for students). The index, which is published by ITU, is based on indicators grouped by three sub-indices: access, usage and skills. Access refers to availability of ICT infrastructure and individuals' access to basic ICT. Usage captures ICT intensity and use. The subcomponent 'ICT skills' includes data on gross secondary and tertiary enrolment ratios (ITU, 2017).

Table 11 Correlation matrix

		IDI	*SDI*	*NRI*
IDI	Pearson correlation	1	0.569**	0.912**
	Sig. (bilateral)		0.000	0.000
	N	48	48	46
SDI	Pearson correlation	0.569**	1	0.596**
	Sig. (bilateral)	0.000		0.000
	N	48	52	47
NRI	Pearson correlation	0.912**	0.596**	1
	Sig. (bilateral)	0.000	0.000	
	N	46	47	47

Notes: **Correlation is significant at 1% level (bilateral)

Source: Own elaboration

On the other side, the NRI is a composite index that has been constructed on the basis of a multi-dimensional concept of ICT impact. The index was built by a group of experts at the World Economic Forum (WEF). The index is compound of different levels. The first level entails four pillars that represent the main dimensions of network readiness: technology, people, governance, and impact (Portulans Institute, 2019).

Analysis of the correlation between the SDI and IDI suggests that students' digitalisation is significantly related with countries ICT development level. In other words, students ICT adoption is linearly related with countries ICT development level. Since correlation is positive, IDI increases as SDI increases. Same results arise when we correlate SDI with the NRI, students ICT adoption is highly correlated with the network-based readiness of each country.

4.6 Relationship between SDI and some PISA's variables

In this section we compare the average SDI by type of country, whether the country belongs to OECD or not, students' gender, grade repetition, parents education and annual household income. Students from OECD countries have a higher SDI than non-OECD countries. This SDI difference is statically significant based on ANOVA (Table 12). The average SDI in OECD countries is higher than in non-OECD countries. Then, we reject the hypothesis that the average SDI is equal.

Table 12 Average SDI by PISA's variables

PISA variables		*Mean*	*N*	*St. dev*	*ANOVA*
OECD country	Yes	0.4942	9006035	0.11791	F = 23,562.01***
	No	0.4829	3544538	0.11655	
	Total	0.4910	12550573	0.11764	
Gender	Male	0.5048	6212468	0.12253	F = 171,403.01***
	Female	0.4775	6338105	0.11099	
	Total	0.4910	12550573	0.11764	
Repetition	Did not repeat a grade	0.5038	10389572	0.11171	F = 79,856.19***
	Repeated a grade	0.4718	1108053	0.12771	
	Total	0.5007	11497625	0.11374	
Highest education of parents (ISCED)	None	0.4037	141702	0.12372	F = 103,336.38***
	ISCED 1	0.4213	446055	0.11711	
	ISCED 2	0.4558	1025454	0.11423	
	ISCED 3B. C	0.4745	460615	0.11353	
	ISCED 3A. ISCED 4	0.4770	2763263	0.11645	
	ISCED 5B	0.4892	1936184	0.11368	
	ISCED 5A. 6	0.5139	5673256	0.11403	
	Total	0.4911	12446529	0.11756	
Annual household income	Less than $A	0.4433	1018524	0.11877	F = 13,357.22***
	$A or more but less than $B	0.4682	444978	0.11057	
	$B or more but less than $C	0.4830	207546	0.11159	
	$C or more but less than $D	0.4795	142252	0.10532	
	$D or more but less than $E	0.4832	130771	0.11249	
	$E or more	0.4943	297600	0.11111	
	Total	0.4633	2241670	0.11602	

Note: ***Statistically significant at 1% level

Source: Own elaboration based on PISA 2018

In respect to gender, male students achieve a higher SDI than female on average. This difference of means is also significant at a 1% level. In terms of grade repetition, the mean SDI is significantly higher in students that did not repeat a grade than in students that repeated a grade. When we analyse the parents' education variable, we observe that the higher the education level, the higher the average SDI achieved is. Being this difference statistically significant based on ANOVA. Lastly, we study the relationship between SDI and the average household income. Results show that the higher the household income, the higher the SDI level is.

5 Discussion

The SDI is aligned with the literature on the subject that recognises the key role the three subcomponents (ICT access, ICT use and ICT engagement) played to better understand the digital gap in education (Juhaňák et al., 2019; Chaudron et al., 2018; Hatlevik et al., 2018). Countries below the average SDI are from developing countries, especially Latin American countries. This finding indorses the differences in terms of ICT access and use between more developed and equalitarian regions and LA unequal environment (Ullah, 2020; Author, 2019; Barrantes Cáceres and Vargas, 2016).

It is worth noting that ICT engagement is the second best subcomponent after ICT use in terms of communalities (Table 3) and average values (Table 7). These results confirm the relevance of the motivational factors to achieve familiarity with ICT, and therefore digital readiness (Juhaňák et al., 2019). Moreover, this subcomponent mainly explains the worse position of South Korea compared to other OECD countries and corroborates Kim et al. (2020) about the weak digital literacy education in that country.

In respect to methodology, the decision to name the PCA first component as ICT engagement emerges from the significance of the ´Perceived autonomy related to ICT use´, ´Perceived ICT competence´ and 'Interest in ICT´ items. As it is explained in the theoretical framework, they are relevant to define the concept of ICT engagement (Meng et al., 2019; Zylka et al., 2015). From an empirical perspective, their linkage is based on the argument that digital skills are positively related with the ICT autonomy and competence (Ryan and Deci, 2017; Wehmeyer et al., 2017; Liu and Wang, 2016) and ICT interest (Chen and Hu, 2020).

SDI can easily be replicated for further years because the methodology and data source used are transparent and replicable. Although the SDI is based on data from 2018, the methodology applied to build the index could be replicated to more recent years. In fact, since the SDI was found to be robust in respect to applying different methodologies of weighting, we can suppose that using equation (2) as a baseline expression of the SDI formulae could be acceptable.

Moreover, due to the COVID-19 pandemic we can suppose that the ICT use subcomponent will be overestimated. During those years of covid social distancing, students needed ICT for schooling and learning at home. Moreover, ICT access at home emerged as the main reason for explaining the digital gap between students who could access and those who could not (Mohd Aba Sha'ar et al., 2023; Guo and Wan, 2022). These digital gap was likely wider in developing countries where students could not assist to schools (caused by covid quarantine, social isolation), and therefore could not have access to ICT at school. On the other side, ICT autonomy and competence could become a critical barrier for students without digital skills.

6 Conclusions

The main objectives of this paper are to measure students' digitalisation at the country level and compare it by discussing the key factors involved in the definition of students' digitalisation. Although literature has explored the ICT adoption among students, there is a lack of a multidimensional index. In this respect, it is of concern if perception factors should be considered for assessing the digitalisation level of a student.

This paper proposes a composite index of student digitalisation named SDI. A factorial analysis based on PISA database for 2018 was conducted to build the SDI. The SDI synthetises students' information about ICT access (devices and connectivity, either available at home or at school), ICT use (internet frequency of use), and ICT engagement (students perception based on their experience with ICT); thus, overcoming the available PISA indexes. Results show that the index is robust to changes in the methodology of weighting. Best positioned countries are developed countries. Besides, the study observes there is a significant correlation between SDI and some international ICT indexes at country level such as the IDI and NRI.

From the explanatory analysis, the SDI is described and compared in relation to some variables such as being an OECD country, household income, gender, grade repetition, and parents' highest educational level. As a result, the average SDI achieves a higher value if data corresponds to an OECD country, if students are male, if the student has not repeated any grade. Moreover, the higher the household income or the parents' educational level is, the higher the SDI will be.

As any composite index, SDI has the advantage of synthetising the complex information the students digitalisation concept entails. In fact, different and complementary sides of ICT adoption in education are included in a single index in order to describe and compare among countries. Without a composite index, comparison among countries in the digital divide will be more difficult. Moreover, the use of indexes is useful for a country to offer a basis for enhanced internal performance. At the moment, we have not find any research building a student digitalisation index based on PISA data.

The SDI provides information as a policy tool in encouraging students' digitalisation. Countries with a low SDI level should develop strategies to enhance their position. The subcomponents levels (Access, Use and Engagement) bring information to a country about the explanatory factors of the SDI level. Since the SDI adds objective and subjective data, we consider this composite index to be a complete measure of students′ digitalisation. Countries at the bottom of the ranking could examine the profile and policies applied in countries at the top of the ranking. Measuring students' digitalisation is also needed to improve their performance to ensure adequate funding and grants for ICT in education. The worst positioned countries in terms of SDI are Dominic Republic, South Korea, Georgia, Morocco and Japan. Based on this information, we can expect the consequences of the quarantine due to covid will be worse for students and parents from these countries.

The proposed index does not pretend to criticise PISA's methodology. On the contrary, the index uses PISA database to build complementary information that could be useful for assessing public policy at the country level. By only looking at the existent sub-indexes, which are applied to different subjects (students, households, and schools) would make the description and comparison among countries a difficult task. Moreover, the index is useful to explain the consequences in the educational field of mass quarantine due to the covid. Less developed countries in terms of students' digitalisation are expected to suffer more as they are less prepared to engage in online education. This disadvantage position is not only explained by their weak ICT access. Students' tendency to connect digital technology also depends on the skill or ability to use the technologies. Children without those skills are also in a worse position, and this situation gets worse if their parents work outside home during the pandemic.

Some of the limitations of the paper are linked to the disadvantages of using composite indexes such as the problems of interpreting and failure to know the distinct contribution of each component. Moreover, there are many different weighting methods that could be used to build the index.

To conclude, the SDI could be a foundation for an appropriate framework for ranking different countries based on the students' digitalisation. SDI is based on multiple indicators and is not affected by any expert opinion or subjective bias. In this sense, the obtained results could be easily utilised for decision making not only of government but also other stakeholders as technological companies.

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Notes

1 Authors can provide this information in case of interest.