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FACTOR ANALYSIS OF MATHEMATICAL AND DIGITAL ABILITIES AND THEIR CORRELATIONS WITH OTHER KEY COMPETENCIES

SKAIČIAVIMO IR SKAITMENINIŲ GEBĖJIMŲ FAKTORINĖ ANALIZĖ IR JŲ RYŠIAI SU KITOMIS BENDROSIOMIS KOMPETENCIJOMIS

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Summary. The purpose of the study is to examine relationships between various mathematical and digital competence skills and abilities and their correlations with other key competencies (native and foreign languages, entrepreneurship, learning to learn, cultural awareness) using data of a nationwide research project conducted in Lithuania in 2014. The main sample consists of 864 adult respondents. Data were gathered through an online survey. Principal Factor Analysis produced five factors: general mathematical and digital ability, general computer using ability, frequency of using computers in different places, frequency of using computers for different purposes, frequency of using smartphones. Better mathematical and digital abilities were found to be associated with younger age and better education, to a lesser extent with living in bigger cities. No significant differences between men and women, also between employed and unemployed were found. Statistically significant correlations of mathematical and digital abilities with other key competencies were found, especially with entrepreneurship and foreign language (English), but also with all the others. Further research is needed to develop statistically sound mathematical and digital competence measurement tools suitable in large scale statistical research.

Keywords: mathematical and digital competence, native and foreign languages competencies, entrepreneurship, learning to learn, cultural awareness, principal factor analysis, correlations, ordinal regression.

Santrauka. Tyrimo tikslas yra ištirti ryšius tarp įvairių skaičiavimo ir skaitmeninių technologijų kompetencijos gebėjimų ir jų koreliacijas su kitomis bendrosiomis kompetencijomis: gimtąja ir užsienio kalbomis, verslumu, mokymusi mokytis, kultūriniu sąmoningumu. Naudojami duomenys nacionalinio mokslinio tyrimo, atlikto Lietuvoje 2014 metais. Pagrindinė imtis susideda iš 864 suaugusių respondentų. Duomenys surinkti naudojant apklausą per internetą. Pagrindinių faktorių analizė išskyrė penkis faktorius: bendrieji skaičiavimo ir skaitmeninių technologijų gebėjimai, bendras gebėjimas naudotis kompiuteriais, kompiuterio naudojimo įvairiose vietose dažnumas, kompiuterio naudojimo įvairiais tikslais dažnumas, išmaniųjų telefonų naudojimo dažnumas. Geresni skaičiavimo ir skaitmeninių technologijų gebėjimai susiję su jaunesniu amžiumi ir geresniu išsilavinimu, šiek tiek susiję su gyvenimu didesniuose miestuose. Nerasta statistiškai reikšmingų vyrų ir moterų skirtumų, taip pat nėra tokių skirtumų tarp dirbančių ir bedarbių. Rastos statistiškai reikšmingos koreliacijos su kitomis pagrindinėmis kompetencijomis, ypač su verslumu ir užsienio kalbos (anglų) kompetencija, tačiau taip pat ir su visomis kitomis. Reikia tęsti mokslinius tyrimus siekiant sukurti statistiškai pagrįstus skaičiavimo ir skaitmeninių technologijų kompetencijos matavimo įrankius, tinkamus didelės apimties statistiniams tyrimams.

Raktažodžiai: skaičiavimo ir skaitmeninių technologijų kompetencija, gimtosios ir užsienio kalbos kompetencijos, verslumas, mokymasis mokytis, kultūrinis sąmoningumas, pagrindinių faktorių analizė, koreliacijos, ranginė regresinė.

INTRODUCTION

Mathematical and digital competencies are two of the eight key competencies which form the framework of key competencies presented in the *Recommendation of the European Parliament and of the Council of 18 December 2006 on Key Competences for Lifelong Learning* (2006). These two competences were included into the nationwide survey which was conducted in the year 2014 as part of a research project funded by the European Social Fund under the Global Grant measure (Suaugusiųjų bendrųjų kompetencijų lavinimo tyrimų ir plėtros platforma (2015), in English: "Adults' general competences' research and development platform"). The other main competences analyzed in the project were: communication in the mother tongue, communication in foreign languages, learning to learn, entrepreneurship, and cultural awareness and expression. Mathematical and digital competence was defined in the survey questionnaire as ability to develop and apply mathematical reasoning in solving different problems; ability reliably, critically and creatively use information society's technologies at house and at work, search, collect and process information using computer programs, internet, social e-communication means: e-mail, e-chat ("Skype", et al.), social communication sites ("Facebook", et al.). As the definition shows, mathematical and digital competence was presented in the survey as one competence, not as two separate ones. Only simple, essentially needed for everyone, mathematical abilities are included in the competence, such as everyday calculations or calculations by heart.

The article focuses on mathematical and digital competence, as defined in the previous paragraph, on abilities which constitute this competence, their inter-relationships, and the relationships of mathematical and digital competence and its parts with the other key competences of the research. Two main problems are at the center of the article: 1) how to measure and evaluate mathematical and digital competence and corresponding abilities of respondents using self-reported questionnaire and advanced measurement scale construction methods, especially factor analysis; 2) what are relationships of these measured abilities between themselves and with other key competences analyzed in the project. The aim of the research was to evaluate mathematical and digital competence of the respondents using various indicators and summarizing measures (factors), and to establish relationships between these indicators and measures, as well as their correlations with other key competences. The object of the article are mathematical and digital competences of adults.

QUESTIONNAIRE AND DATA COLLECTION

Empirical data of the research were collected using structured questionnaire consisting of 112 questions in 13 domains (blocks). Blocks of questions used in the article are presented in the Table 1.

Table 1

Domains (blocks) of questionnaire questions used in the article

Domain	Number of questions	Example	Scale
General evaluation of mathematical and digital abilities	7	Ability to perform simple calculations by heart (add, subtract, multiply, divide	1 – Very well, 2 – Well, 3 – Average, 4 – Poorly, 5 – Don't know
Computer literacy related abilities	9	Ability to use information technology for communication: e–mail, chat programs ("Skype", etc.), social sites ("Facebook", etc.)	1 – Very well, 2 – Well, 3 – Average, 4 – Poorly, 5 – Don't know at all
Frequency of using computers in different places	4	Where and how often do you use computer at work?	1 – Everyday or every work day, 2 – Most days per week, 3 – 1–2 days per week or several days per month, 4 – 1–2 days per month or even less often, 5 – Don't use at all
Frequency of different goals of using computer	5	How often do you use computer for work?	The same as above
Frequency of different goals of using smartphone	5	How often do you use smartphone for work?	The same as above except one more answer: Don't have smartphone
Self-evaluation of mathematical and digital competence of a respondent	1	How do you estimate your mathematical and digital abilities?	See Figure 1.

All of these questions are of ordinal type. More detailed descriptions of the questions are in the results‘ part of the article, in tables 4–7, 9, 11 and Figure 1.

Statistical data analysis methods. Statistical data of the research were processed using IBM SPSS Statistics software package, version 22.

Correlations between data variables were evaluated using Pearson (for correlation matrices used in factor analyses), Spearman (correlations between interval measurement level variables) or Kendall‘s tau (correlations between respondents‘ ordinal level responses to questionnaire‘s questions) coefficients.

Factor analysis was performed using Principal Factors (axis) method to extract factors and Direct Oblimin method to rotate them. Number of factors was determined using the "standard" eigenvalues‘ cut-off of 1; however, only clearly interpretable factors were retained. Factor scores were calculated using regression method (DiStefano et al., 2009).

Ordinal regression (proportional odds model) was used to analyze how self-evaluated mathematical and digital competence is related to respondents sex, age, education, habitat and employment status.

RESULTS OF THE RESEARCH

Respondents. 864 surveys were accepted as valid. 60 percent were women, 40 percent men. Age of respondents was from 18 to 83 years, M = 37,0, SD = 13,7, Md = 33,0. Most respondents (62 percent) had at least college education, were married (45 percent) and lived in cities (60 percent; 23 percent in smaller towns, 17 percent in rural area). 25 percent of them were employed or self-employed, 32 percent unemployed, 4 percent pensioners, other 39 percent were of unknown status.

Mathematical and digital competence: self evaluation by respondents. 832 respondents answered the question "Please evaluate your competence in mathematics (calculations) and information society technologies". As Figure 1 shows, even 94 percent the respondents think that this their competence is very good, good or at least average.

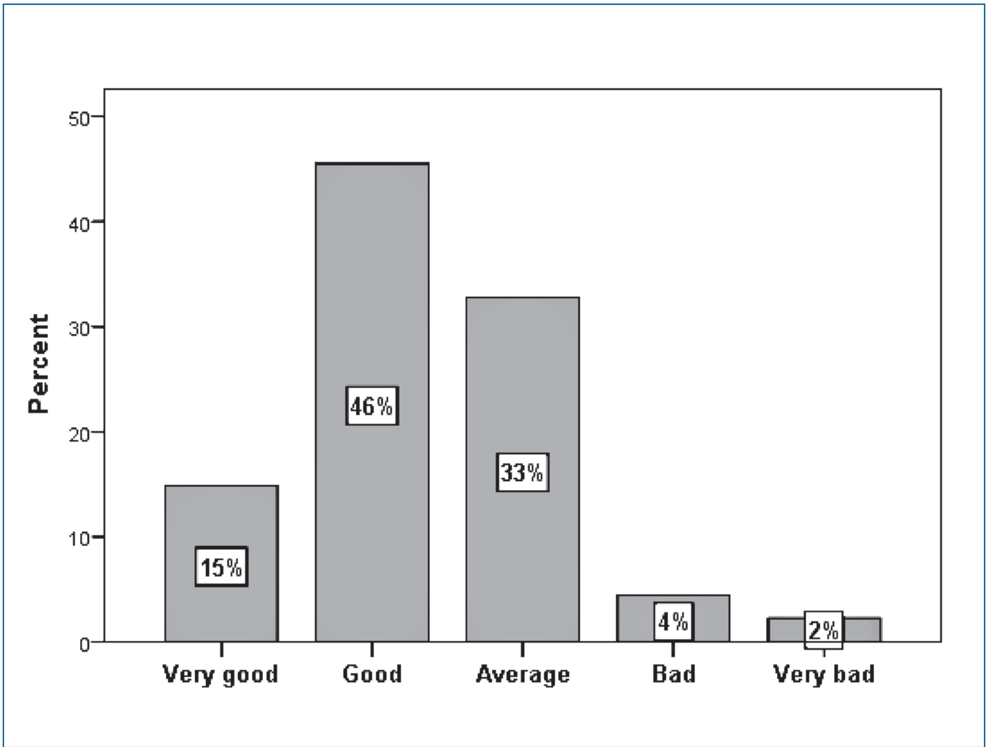

Figure 1. **Evaluation by respondents of their competence in simple mathematics and information society technologies.**

In order to see how this competence depends on demographical characteristics of the respondents, answers "bad" and "very bad" were combined, and ordinal regression was performed using this new variable as dependent. The regression was highly significant ($p < 0.001$), Cox & Snell coefficient = 0,17, Nagelkerke = 0,19. Statistically significant predictors are presented in Table 2.

Table 2

Statistically significant demographic predictors of self-evaluated mathematical and digital competence

Predictor	Regression coefficient	95 % Confidence interval	
		Lower Bound	Upper Bound
Age	.021	.014	.029
Lives in a big city	–.54	–.83	–.25
Education less than secondary school	1,16	.71	1.60
Secondary school or higher education (no college or university)	.60	.38	.82

Note. $p < .001$ for all predictors in the table.

As expected, mathematical and digital competence is positively influenced (increased) by living in big cities, and negatively influenced by age and lower education. There was no significant difference between men and women.

Adding employment status (employed vs unemployed) to the predictors doesn‘t change the main results of the regression. Employment status itself is non-significant (p = .21).

Inter-correlations between mathematical and digital abilities and their factor analysis. Inside domains, answers to all questions correlate positively and significantly, p < .001, with only one exception: there is no correlation between frequency of using computer at work and frequency of using computer at friends, relatives, acquaintances. The general information about these correlations is presented in Table 3.

Table 3

Kendall's tau-b correlation coefficients between questions inside every domain of the questionnaire.

Domain	Correlation coefficients		
	Average	Minimum	Maximum
General evaluation of mathematical and digital skills	**.49**	.31	.68
Computer literacy related skills	**.55**	.38	.73
Frequency of using computers in different places	**.29**	.06	.54
Frequency of different goals of using computer	**.38**	.14	.63
Frequency of different goals of using smartphone	**.30**	.16	.49

Such patterns of correlations inside domains indicate good possibilities to factorize these correlations in order to find out higher order dimensions explaining the correlations. Such factor analyses were performed as described in “Statistical data analysis methods”. Table 4 summarizes main results of these analyses.

Table 4

Main results of factor analyses of correlations inside questionnaire domains

Domain	Number of factors	Percentage of explained variance after extraction	Meaning(s) of factor(s)	Factor eigenvalues after extraction
General evaluation of mathematical and digital skills	1	53.1	General mathematical and digital ability	3.7
Computer literacy related skills	1	64.6	General ability to use computer	5.8
Frequency of using computers in different places	2	52.5	1. Frequency of using computers not at work. 2. Frequency of using computers at work.	2.5[a] 1.1[a]
The same outside work and home[b]	1	48.0	Frequency of using computers outside work and home	2.4
Frequency of different goals of using computer	1	46.7	Frequency of different goals in using computer	2.3
The same without using for work[c]	1	53.6	Frequency of different goals in using computer not for work	2.1
Frequency of different goals of using smartphone[d]	1	34.8	Frequency of different goals in using smartphone	1.7

a. These eigenvalues are after rotation because two factors were extracted and rotated.

b. Question about using computer at work was deleted because many respondents are unemployed. Question about using computer at home was deleted because of its relatively low discriminative power between respondents: 85 percent of them say that they use computer at home everyday or most days per week. Consequently, this question poorly correlates with the other questions.

c. Question about using computer for work was deleted for the same reason as described in *b*.

d. Questions were answered by for respondents who said that they had a smartphone.

Factors confirm unidimensionality of domains, with one exception that using computer at work separates from using computer in other places, e.g. at home. This exception can be easily explained: frequency of using computer at work reflects not only the corresponding ability of a respondent but also strongly depends on his or her job and if he or she has job at all. These analyses are useful not because they provide some new insights into the structure of mathematical and digital competence but mostly because they summarize questions of the domains and greatly decrease number of variables for the following analysis.

Next seven tables (Tables 5–11) present factor loadings and communalities for all of the factors.

Table 5.

Factor loadings and communalities of the general mathematical and digital ability factor

Ability	Loading	Communality
To calculate using electronic devices, such as calculators, mobile phones	.82	.67
To use mobile phone for communication and other purposes	.80	.65
To use ATM	.76	.58
To perform everyday calculations when buying in shops, paying for communal services, etc.	.71	.50
To use a computer	.71	.50
To use GPS when driving, walking, etc.	.66	.43
To add, subtract, multiply, divide numbers by heart	.62	.38

As Table 5 shows, loadings are not very different. Probably all these abilities are rather equally related to mathematical and digital competence. Factor explains most of these abilities well, at least at the 50 percent level, only ability to use GPS and count by heart are explained worse.

Table 6

Factor loadings and communalities of the general computer literacy factor

Ability	Loading	Communality
To write and read using text processing software (e.g. Microsoft Word, Open Office, etc.)	.87	.76
To calculate and draw diagrams using spreadsheets (Microsoft Excel, Open Office, etc.)	.86	.73
To create presentations (Microsoft Power Point, etc.)	.86	.73
To use information services for personal and work purposes	.83	.69
To find and select the necessary information via the internet	.81	.66
To understand and apply juridical and ethical norms related to information technologies	.81	.66
To use in communication (e-mail, chat programs, social sites)	.78	.60
To use database systems (Microsoft Access, etc.)	.72	.53
To understand and apply computer health and safety rules (work pauses, posture, workplace ergonomics, etc.)	.68	.46

These abilities are explained by the factor even better than abilities of the previous domain. Most abilities are explained at least by 60 percent (of their variances). The lowest position in the factor of the ability of understanding and applying computer health and safety rules probably indicates some negligence of Lithuania's adult population of these rules. Indeed, answers of respondents to this question show that most of them (32 percent) estimate this ability as "average", and 22 percent estimate it as even worse. On the contrary, ability to use text processing software is mostly estimated as "very good" and "good" (32 percent and 33 percent of respondents), and only 35 percent of them estimate this ability as average or worse.

Table 7

Factor loadings and communalities of the factors representing frequency of using computer in different places

Frequency of using computers	Loading		Communality
	Factor 1	Factor 2	
At friends, relatives, acquaintances	.86	−.14	.67
In public places (libraries, internet cafés, etc.)	.83		.67
In street, voyage, nature, etc.	.80		.60
At meetings, conferences, lectures, etc.	.50	.28	.43
At home	.29	.21	.17
At work		.79	.61

Note. Loadings less than .10 are suppressed and not presented in the table.

As was previously mentioned, the first factor was defined as frequency of using computers not at work, and the second factor was defined as frequency of using computers at work. Using computers at home clearly differs from using computers in all other places: this question essentially is not explained by factors. This is probably because using computer at home is so commonplace nowadays (85 percent of the respondents say that they use computer at home everyday or most days per week) that such a use is little related to the use of computers in all other places; consequently, correlations of this question with others in the same domain are weak, and the question cannot belong to any of the factors. Therefore this question was deleted and the factor analysis was repeated. Question about using computer at work was also deleted because it introduces essential non-homogeneity of factor analysis sample: about half of the respondents are unemployed, they cannot use computer at work. See new results in Table 8.

Table 8

Factor loadings and communalities of the factors representing frequency of using computer outside work and home

Frequency of using computers	Loading	Communality
In public places (libraries, internet cafés, etc.)	.85	.72
At friends, relatives, acquaintances	.78	.61
In street, voyage, nature, etc.	.77	.60
At meetings, conferences, lectures, etc.	.58	.34

Similarly problematic was question about using computer for work in factor analysis of questions about frequency of using computer for different goals, see Table 9.

Table 9

Factor loadings and communalities of the factor representing frequency of using computer for different goals

Frequency of using computers	Loading	Communality
For communication	.79	.63
For learning	.78	.61
For leisure activities	.70	.48
For household tasks (communal payments, e-commerce, etc.)	.65	.42
For work	.45	.20

Frequency of using computers for work has relatively low communality in this factor (Table 9), therefore it was decided to repeat the factor analysis without this question (see Table 10 and also the commentary after Table 7).

Table 10

Factor loadings and communalities of the factor representing frequency of using computer for different goals but not for work.

Frequency of using computers	Loading	Communality
For communication	.83	.68
For leisure activities	.75	.56
For learning	.73	.54
For household tasks (communal payments, e-commerce, etc.)	.60	.36

Now one "clean" factor was obtained.

Table 11

Factor loadings and communalities of the factor representing frequency of using smartphone

Frequency of using computers	Loading	Communality
For learning	.74	.54
For household tasks (communal payments: e-commerce, etc.)	.68	.47
For leisure activities	.57	.32
For work	.48	.23
For communication	.43	.18

Low communality of the question about using smartphone for communication can be explained by the very high percentage of smartphones' usage for communication everyday or most days per week: 54 percent of respondents in our sample have smartphones, and 93 percent of them use them everyday or most days per week; consequently, answers to this question are too similar and too little related to other answers.

Correlations between mathematical and digital competence factors. We expect these factors to be more or less correlated. In order to test this and to analyze pattern of these correlations, they were evaluated using Kendall‘s tau-b coefficient; also respondent‘s self-evaluated mathematical and digital competence was included (see Table 12).

Table 12

Correlations between factors of mathematical and digital abilities (Kendall's tau-b coefficients)

	General mathematical and digital ability	General computer using ability	Frequency of using computer outside work and home	Frequency of different computer using goals not for work	Frequency of using smartphone	How do you estimate your mathematical and digital abilities?
General mathematical and digital ability	–					
General computer using ability	.51	–				
Frequency of using computer outside work and home	.18	.24	–			
Frequency of different computer using goals not for work	.30	.38	.35	–		
Frequency of using smartphone	.10	.13	.33	.41	–	*
How do you estimate your mathematical and digital abilities?	.42	.54	.19	.31	.09	–

Note. All of the correlations are significant at least at the .01 level, only significance of the correlation between “Frequency of using smartphone” and “How do you estimate your mathematical and digital abilities?” is $p = .021$.

As expected, the general mathematical and digital ability is rather strongly related to the general computer using ability. Important result is also quite strong correlations between respondents' self-evaluated mathematical and digital competence and the corresponding factor together with general computer using ability.

Abilities' dependence on demographic variables. The obtained factors were used to explore possible differences between sub-populations of the research and relationships with essential demographic variables.

Mann-Whitney test was used to see if the factors differ between men and women. No significant differences were found. Employed and unemployed also did not differ significantly. It seems that previously often reported gender and unemployment gaps in mathematical and digital abilities (e.g. *Komisijos komunikatas Europos parlamentui, tarybai, Europos ekonomikos ir socialinių reikalų komitetui ir regionų komitetui* (2007)) either do not exist any more in Lithuania, or are at least essentially less noticeable than 5–10 years ago. However, such a conclusion should be approached with caution in the context of the presented research: data were collected mostly via internet, therefore those respondents who are less computer and internet proficient most likely were less inclined to participate in the survey. Respondents' selection bias seems very probable in such a situation.

Another situation is with age, education and habitat: these variables do influence mathematical and digital abilities represented by the factors (Table 13).

Table 13

Kendall's tau-b correlations between age, education, habitat and mathematical and digital abilities

	Age	Habitat	Education
General mathematical and digital ability	–.14**		.13
General computer using ability	–.18**	–.10	.21
Frequency of using computer outside work and home	–.26*	–.10*	
Frequency of different computer using goals not for work	–.21**	–.15*	.13*
Frequency of using smartphone			
How do you estimate your mathematical and digital abilities?	–.11**	–.15*	.21

Note 1. Only statistically significant correlations are presented in the table.
Note 2. Habitat categories are ordered in such a way that increasing values mean moving away from big cities towards rural areas.

As can be seen from Table 13, older people still have worse mathematical and digital competence. Better education, on the contrary, is related to better competence in computers, simple mathematics, and ability to use various information and communication devices. Mathematical and digital competence is less dependent on habitat, however, this competence still statistically significantly worsens with decreasing number of inhabitants in place of respondent's habitat.

Relationships of mathematical and digital competence with the other key competences. There were other key competences which were analyzed in the same project (*Suaugusiųjų bendrųjų kompetencijų lavinimo tyrimų ir plėtros platforma* (2015)). Large studies which analyze different key competences in the same research frame are not very often, therefore it seems expedient to use this advantage of the collected data. Unfortunately, sample sizes to estimate correlations of mathematical and digital abilities with other key competences are much less because of the research design: most respondents answered only to one questionnaire about one key competence. However, there are respondents who answered questionnaires about two or even more key competences. These data can be used for preliminary estimation of the relevant correlations. Their sample sizes range from 24 to 100. This is enough to find out correlations of at least average size. These correlations are presented in Table 14.

Table 14

Correlations of mathematical and digital abilities with other key competences via Kendall's tau-b coefficient

Competence or ability	General mathematical and digital ability	General computer using ability	Frequency of using computer outside work and home	Frequency of different computer using goals not for work	Frequency of using smartphone	How do you estimate your mathematical and digital abilities?
Native language competence (factor)	.17	.21				.19
Can you communicate in English? (question)	.27	.33	.37		.31	.31
How do you estimate your entrepreneurship ability?	.29	.32	.25	.29	.44	.46
How do you estimate your ability to learn?	.22					
"Popular" culture aspects	.26					
Interests related to art	.20	.18	.21		.31	.30
Respect and tolerance				.23		

Note 1. Only statistically significant correlations are shown in the table.

Note 2. Native language competence is a factor which was obtained from five questions about native language abilities in a similar way as factors described in the current article.

Note 3. English language was chosen to represent foreign languages competence because most respondents (63 percent) say that they can communicate in this language.

Note 4. Cultural awareness and cultural literacy was represented by four factors – results of factor analyses similar to those which were described here. These factors were: 1) "Classical" culture aspects (reading books, visiting museums, theaters, listening to classical music, etc.), 2) "Popular" culture aspects (watching movies, listening to pop music, watching TV performances), 3) Art related interests (responses to statements, such as "I am interested in art", "I understand art pieces", etc.), 4) Respect and tolerance towards other people, groups, nations. "Classical" culture aspects did not significantly correlate with any of the mathematical and digital abilities' variables, therefore they are not presented in the table.

Discussion. Interpretation and comparison of these correlations is not easy because they were estimated using different sample sizes, in some cases very different, up to four times. However, some of these results seem interesting. E.g., rather surprising (and maybe not very laudable) are relatively high correlations of mathematical and digital abilities with communication skills in English. Note also high correlations with entrepreneurship skills. Cultural awareness and literacy seem less related to mathematical and digital competence, however, quite a few significant correlations can be seen for "Interests related to art". Ability to learn demonstrates only one significant correlation but there are some other of similar size which are not significant probably only because of too small a sample.

After all the results, it seems that of these five factors more important and informative are the general mathematical and digital ability factor together with the general computer using ability factor. Evaluation of the competence by a direct question to respondents also seems practically useful, at least for purposes of statistical research.

The five mathematical and digital abilities' factors produced in the analysis proved to be useful and preliminary valid in exploring relationships between different abilities including those related to other key competences. Some deficiencies of these factors also emerged which is not surprising because initially the choice of questions of the questionnaire, their formulations and the whole research design were not intended to be used for development of new scales with good measurement properties.

CONCLUSIONS

Based on correlations between mathematical and digital abilities in the data of the questionnaire, two main and three auxiliary factors were established: general mathematical and digital ability and general computer literacy (main factors); frequency of using computer outside work and home; frequency of different computer using goals not for work (but for other purposes); frequency of using smartphones (auxiliary factors).

Mathematical and digital competence is positively related to other key competences, especially to entrepreneurship and foreign languages competences, but also to cultural awareness, native language competence and learning to learn.

In Lithuania, older age and lower education are still negatively associated with mathematical and digital competence; to a lesser extent this is true also for living in more rural places.

Our data and analysis did not show any significant differences in mathematical and digital competence between men and women, between employed and unemployed.

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