Lifelong Learning: Formal, Non-Formal, and Informal Learning in the Context of the Use of Problem-Solving Skills

STRUCTURED PRACTITIONER NOTES

What is already known about this topic
- Previous studies have indicated a positive association between formal education and the adults' lifelong learning regarding problem-solving in TRE.
- To support lifelong learning, people should be equipped with 'personal tools.
- It has been argued that informal learning activities are even more significant than formal activities.

What this paper adds
- Understanding of how formal, non-formal, and informal learning are associated with problem-solving skills in TRE.
- The findings suggest that adults' learning ecologies are a combination of formal, non-formal, and informal learning.
- An important implication of this study is that our results clearly indicate that informal learning activities are highly associated with sufficient problem-solving skills in TRE.

Implications for practice and/or policy
- This kind of knowledge can be applied to guide the research, policies and practices that support learning ecologies in the digital era.
- This knowledge can be used a start for creating safe and supportive environments for informal learning in non-formal and formal settings.

Abstract

The evolving technological landscape in the digital era has a crucial influence on lifelong learning and the demand for problem-solving skills. In this article, we identify associations between formal, non-formal and informal learning with sufficient problem-solving skills in technology rich environments (TRE). We focus on adults' problem-solving skills in TRE as a novel approach to investigate formal, non-formal and informal learning based on data from the Programme for the International Assessment of Adult Competencies (PIAAC). This programme measured 16 to 64 year-old adults' proficiency in problem-solving skills in TRE. The total sample size was 61,654 individuals from 13 European countries. Our results clearly indicate that the skill levels of more than 50% of adults aged 16–64 years old seem to be insufficient to cope

effectively in TRE. The findings suggest that the learning ecologies of adults are a combination of formal, non-formal, and informal learning activities. The overall level of problem-solving skills in TRE was higher among individuals who indicated that they have participated either formal or non-formal learning activities, compared to those who have not. However, interestingly, the association between formal learning and problem-solving skills in TRE was not major. Instead, our results clearly indicate that informal learning seems to be highly associated with sufficient problem-solving skills in TRE. In practice, we outline those formal, non-formal and informal learning activities that adults perform when applying the skills in TRE. By recognising these activities undertaken by sufficient problem solvers, we can promote lifelong learning skills. Our findings can also be used as a starting point for future studies on lifelong learning.

Keywords: Lifelong learning; learning ecology; formal, non-formal and informal learning; PIAAC large-scale assessment data; problem-solving in technology-rich environments

Introduction

In this article, we apply the Programme for the International Assessment of Adult Competencies (PIAAC) large-scale assessment data to synthesise and reflect on the concept of 'lifelong learning ecologies', with a particular focus on empirical evidence obtained through an analysis of adults' skills together with their activities. Particularly, this study identifies associations between the contexts, resources, activities and relationships in a continuum from formal to informal learning. Our approach is grounded on the notion that the evolving technological landscape in the digital era has a crucial influence on lifelong learning. The central goal of lifelong learning is to guarantee sufficient know-how for all citizens, which is in line with the changing needs of work and everyday life. Regarding these needs, it is generally agreed that this century increasingly requires skills to solve problems in technology-rich environments (TRE). Thus, we concentrate on how formal, non-formal and informal activities are associated with these problem-solving skills in TREs.

Theoretical Background

The concept of learning ecology is based on the ecological systems theory by Bronfenbrenner (1986, 1989), who claimed: 'The ecology of human development is the scientific study of the progressive, mutual accommodation throughout the life course between an active, growing human being and the changing properties of the immediate settings in which the developing person lives' (p. 188). In practice, learning ecologies combine different spaces and contexts simultaneously during the life course (Jackson, 2013), including formal, non-formal and informal settings in both physical and virtual spaces (Barron, 2006). Furthermore, the technological landscape is constantly influencing learning ecologies by blurring the lines between formal and informal learning.

The roots of learning research are concerned with formal learning contexts (Kolb & Kolb, 2017). The extant research addresses formal, non-formal and informal learning**.** Formal learning is typically connected to educational systems. It is compulsory, steered by the curricula, and highly orchestrated by the teacher (Eshach, 2007). Furthermore, formal learning is intentional and geared towards achieving a diploma or certificate (Cedefop, 2014). In contrast, non-formal learning usually takes place outside the institutional context. However, it is often organised by institutions and organisations, and it is usually led by a teacher or guide and often not evaluated (Cedefop, 2014; Eshach, 2007; Schugurensky, 2000). The main differences between formal and non-formal learning is that the latter is generally voluntary and the learner's attendance is not mandatory. Moreover, it does not lead to a certificate or diploma, although participants are sometimes provided with proof of attendance. Finally, the teacher's role may be less important, and learners may only be loosely connected to the teacher in non-formal settings.

In contrast to the institutionalised approach, informal learning is ubiquitous (Eshach, 2007; Schugurensky, 2000). Informal learning is defined as learning from daily life actions related to work, family or leisure activities, which are often spontaneous, unplanned and unstructured (Cedefop, 2014; Eshach, 2007; Marsick & Watkins, 2001). In addition, it exists inside and outside of formal education, e.g. the institutional context. However, when informal learning takes place in educational institutions, it is not based on classroom activities, and it is not necessarily structured. Informal learning also occurs in other formal contexts, such as

networking, coaching, and mentoring (Marsick & Watkins, 2001). Bednall et al. (2014) claim that informal learning can be stimulated by formal mechanisms, and it has been argued that informal learning activities are even more significant than formal activities (Za, Spagnoletti, & North-Samardzik, 2014). It is generally agreed that informal learning has an influence on lifelong learning (Fevre, Gorard, & Rees, 2000).

There is a critical notion that previous research has usually focused on either formal, non-formal, or informal settings, neglecting the potential of digital learning ecologies. In digital learning ecologies, the borders between formal, non-formal, and informal learning typically overlap (Schugurensky & Myers, 2003). The internet and novel technological solutions have had an impact on the creation of rich digital learning ecologies that enable new ways for people to interact, thereby supporting the exchange of information and offering tools and artefacts. For example, social media is a common practice that combines formal, non-formal, and informal learning (Dabbagh & Kitsantas, 2012; Yasar & Karadeniz, 2011). At its best, mobile learning can also reach synergy between formal, non-formal, and informal learning (Beale, 2006; Laru & Järvelä, 2015; Malcolm, Hodkinson, & Colley, 2003; Sharples, 2006). According to Looi et al. (2009), we should more deeply understand how adults learn in these new formal, non-formal and informal learning settings and how digitalisation reshapes lifelong learning.

Lifelong learning links all areas of life: a) from childhood to old age; b) from the workplace to home; and c) from formal and non-formal to informal contexts (Laal, 2011). To support lifelong learning, people should be equipped with 'personal tools, such as memory aids, concept and topic maps, case archives and communication devices that are highly portable, individual, unobtrusive, available anywhere, adaptable, persistent, useful and intuitive' (Sharples, 2000, p. 179). In contemporary society, adults' lifelong learning (Goos, 2013) and personal learning environments are highly influenced and expanded by technological developments (Dabbagh & Kitsantas, 2012; Manca & Ranieri, 2013), which increasingly present them with opportunities to develop their skills and actively engage in lifelong learning (van Laar, van Deursen, van Dijk, & de Haan, 2017).

This study grounds on the problem-solving definition of OECD (2014) which defines the problem-solving skills in technology rich environments (TRE) in the following way:

> Problem-solving in technology-rich environments involves using digital technology, communication tools and networks to acquire and evaluate

> information, communicate with others and perform practical tasks. The first PIAAC problem-solving survey will focus on the abilities to solve problems for personal, work and civic purposes by setting up appropriate goals and plans, accessing and making use of information through computers and computer networks (p.4).

As a direct result of current technological developments, problem-solving in TRE is considered one of the most important skills to possess in benefiting from the affordances of formal, non-formal, and informal learning contexts (Frank & Castek, 2017; Goos, 2013; Rosen, 2014). Previous studies have indicated a positive association between formal education and the adults' problem-solving skills in TRE. Furthermore, skills used outside of work seem to be clearly related to problem-solving skills in TREs (Hämäläinen, De Wever, Malin & Cincinnato, 2015; Hämäläinen, De Wever, Nissinen & Cincinnato, 2019). Recently, assumptions have been made about how formal, non-formal and informal learning activities are associated with lifelong learning in the digital era. To reshape our understanding of learning ecology and encapsulate the idea of lifelong learning, this study aims to investigate how formal, non-formal, and informal learning activities are associated with sufficient problem-solving skills in TRE. The research question for this study is as follows:

RQ: How are formal, non-formal, and informal activities associated with sufficient problem-solving skills in TRE?

Methods

Before the PIAAC, no international large-scale assessment data on adults' skills were available. Therefore, the PIAAC offers new possibilities for investigating how formal, non-formal and informal learning activities are associated with lifelong learning in the digital era. The PIAAC survey, conducted by the Organisation for Economic Co-operation and Development (OECD), measured 16 to 64 year-old adults' proficiency in key information-processing skills in TRE, such as literacy, numeracy and problem-solving skills. In addition, rich background data on the respondents' socio-demographic characteristics, education, working life, interests and activities were collected through questionnaires. The first round of the PIAAC

survey was conducted during 2011–2012, and it yielded nationally representative data sets from 24 countries, consisting of 166,000 individuals in total.

In the PIAAC, adults' problem-solving proficiency in TRE was determined through collections of computer tasks of varying difficulty. The more difficult the tasks were that the individual successfully completed, the higher his/her problem-solving score was. The score range was divided into four levels. People who scored level 1 were only able to solve simple problems with most common technology applications. Those who failed to reach level 1, or who had too little or no computer experience or otherwise retreated from taking the computer-based test, were ranked below level 1. Level 2 required the ability to use more specific technology applications. Level 3 required more advanced integration and inferential reasoning (see OECD, 2016). In the present study, it was considered that from the individual's perspective, levels 2 and 3 represented sufficient problem-solving skills in TREs, considering the challenges of working and personal life in the twenty-first century.

In this study, we examined the association between sufficient problem-solving skills in TRE (defined as achieving level 2 or 3 in PIAAC) and various activities related to formal, non-formal or informal learning. We analysed the PIAAC first-round data from 13 European countries (Austria, Belgium, Czech Republic, Denmark, Finland, Germany, Ireland, Netherlands, Norway, Poland, Slovak Republic, Sweden and the United Kingdom) that participated in the PIAAC assessment of problem-solving skills in TRE. The current interest of this study was not to compare countries; therefore, we pooled the data from the 13 countries. Furthermore, as our main interest was concerned with how the technological landscape is associated with learning ecologies, we focussed on the data of problem-solving skills in TRE. The total sample size of these countries was 61,654 individuals.

To tackle the research question, we selected the most appropriate variables from the PIAAC questionnaire data. Formal learning was measured with two questions about the respondents' formal learning activities during the last 12 months. The first was whether the respondent participated in any such activities. Here, the options were (1) no formal studies, (2) participated in formal adult education and training, and (3) student in a regular programme. If he/she did participate, the respondent was asked to indicate to which International Standard Classification of Education (ISCED) level the activities corresponded. The amount of non-formal learning was measured by the length of time the respondent spent on such activities

during the last 12 months. For convenience, the time reported originally in hours was converted into days and classified into five categories: (1) not at all, (2) 1–2 days, (3) 3–5 days, (4) 6–10 days and (5) 10 days or more. Informal learning was determined through questions about the extent of free-time activities that required the use of reading (e.g. reading books or articles), writing (e.g. writing reports or e-mails), numeracy (e.g. calculating percentages or preparing charts) or ICT (e.g. using the internet or some software) skills. The items measuring the extent of various activities were summed up as indexes. In our analyses, we employed five-point categorisations of these skills-use indexes: (1) very little, (2) little, (3) moderately, (4) much, and (5) very much.

To answer the research question, we first examined the prevalence of sufficient problem-solving skills in the subgroups based on various learning activities. We calculated the estimated percentages of individuals scoring level 2 or 3 using the statistical methodology recommended by the PIAAC Consortium (OECD, 2013). That is, sampling weights were employed in all calculations, and the percentages were estimated using all 10 plausible value scores measuring individuals' proficiency in problem-solving in TRE. Second, we fitted binary logistic regression models to analyse the associations between sufficient problem-solving skills in TREs and formal, non-formal and informal learning activities. The PIAAC_Tool macros (Denis, 2014) for SAS software, provided by the Consortium, were employed in all statistical computations.

Results

In the PIAAC data set of 13 European countries, a total of 43.7% of the respondents scored level 2 or 3 in problem-solving in TRE. Thus, clearly more than half of the 16 to 64 year-old adults seemed to have insufficient skills. The share of respondents performing at level 3 (indicating strong proficiency in problem-solving in TRE) did not exceed 7.8%. The frequency of level 2 and 3 skills was consistently related to the respondent's age, educational background and occupation. In the two youngest age groups, 16–24 and 25–34, more than half of the respondents (53.4% and 54.8%, respectively) had sufficient skills, whilst in the oldest age group (55–64), the corresponding proportion was only 22.1%. Among adults with a university degree (ISCED 5A or ISCED 6), no less than 62.7% had sufficient skills, whilst the respective

percentage among adults educated less than ISCED 3 was 29.6%. As for occupation, similar observations can be made. Among adults with elementary or semi-skilled blue-collar occupations, less than 30% had sufficient problem-solving skills in TRE. Among adults with skilled occupations, this proportion was 57.4%.

Our aim was to examine the associations of formal, non-formal and informal learning activities, as manifested in the PIAAC variables, with sufficient problem-solving skills in TRE. We first considered the formal and non-formal learning according to descriptive statistics. Tables 1 and 2 show the percentages of people with level 2 or 3 problem-solving skills in the subgroups determined by the variables of formal and non-formal learning. According to the results, the overall level of problem-solving skills in TRE is higher among individuals who have had either formal or non-formal learning activities, compared to those who have not. The level of formal studies seems to have a strong association with sufficient problem-solving skills in TRE, although it is necessary to note that participants of ISCED 5 and ISCED 6 studies tend to be young. The length of non-formal studies seems to play a positive although clearly smaller role.

Table 1

Percentages of Individuals with Sufficient (level 2 or 3) Problem-Solving Skills in TRE in Subgroups of Formal Learning Activities

Formal studies during the last 12 months	*n*	*Level 2 or 3 problem-solving skills in TRE (%)*
No formal studies	43421	39.1
Participated formal adult education or training	7965	51.6
Studied in regular program	10260	61.7
Level of formal studies during the last 12 months	*n*	*Level 2 or 3 problem-solving skills in TRE (%)*
No formal studies or level below ISCED 3	47782	40.1
ISCED 3	5795	51.6
ISCED 4	832	53.4
ISCED 5 or ISCED 6	7245	69.4

Table 2

Percentages of Individuals with Sufficient (Level 2 or 3) Problem-Solving Skills in TRE in Subgroups of Non-Formal Learning Activities

Non-formal studies during the last 12 months	*n*	*Level 2 or 3 problem-solving skills in TRE (%)*
No non-formal studies	29831	36.1
Participated in non-formal studies	31823	50.9
Time spent in non-formal studies during the last 12 months	*n*	*Level 2 or 3 problem-solving skills in TRE (%)*
No non-formal studies or time unknown	29831	36.1
1–2 days	8814	45.0
3–5 days	8658	52.3
6–10 days	6249	54.0
more than 10 days	7980	54.4

We tested the statistical significance of the association between sufficient performance in problem-solving in TRE and formal and non-formal learning with the help of binary logistic regression models. The probability of level 2 and 3 performance was the response, and formal and non-formal learning activities (presented in Tables 1 and 2) were the explanatory variables. All explanatory variables appeared highly significant ($p < 0.001$). The explanatory power, measured by Nagelkerke's R squared, of the two formal learning variables (Table 1) was rather low at 4.8%. The respective R squared of the non-formal variables (Table 2) was even smaller at only 3.4%. When both the formal and non-formal learning variables were put to the same model together, all were still statistically significant and the R squared increased to 9%. It seems that the PIAAC variables for formal and non-formal learning activities, although significant, do not predict very strongly the probability of an individual having sufficient problem-solving skills. The increase of R squared suggests that formal and non-formal learning activities do not necessarily overlap much; those who participate in formal studies do not necessarily participate in non-formal studies at the same time.

The informal learning activities were measured by the extent various skills (reading, writing, numeracy and ICT) were used in free-time activities. The percentages of individuals with level 2 or 3 problem-solving skills in the skills-use subgroups are given in Table 3. The extent of free-time skills use seems to be strongly and consistently associated with problem-solving performance, regardless of the specific skills used. The strongest association of the four was the use of ICT skills: more than 60% of adults who used them very often had level 2 or 3

skills, whilst among those who used them very little, the percentage was only about 16%. This percentage was also small (19%) among those who read very little. However, the number of such individuals was rather small compared to the other subgroups.

When put to a logistic regression model together, all four skills-use variables of Table 3 were statistically highly significant ($p < 0.001$) predictors of level 2–3 problem-solving skills in TRE. The Nagelkerke's R squared of this model of four explanatory variables was 18%, clearly higher than that of the formal and non-formal learning variables separately or combined. This indicates that informal learning through all kinds of everyday activities is positively associated with having sufficient problem-solving skills in TRE.

Finally, we put the formal, non-formal and informal activities together into one logistic regression model to assess and compare their importance in having sufficient problem-solving skills in TRE during the life course. The results are given in Table 4. The Nagelkerke's R squared of this model was 21.3%, which is slightly larger than the R squared of the model with informal learning alone (18%). This smallish increase suggests that informal learning is correlated with formal and non-formal learning activities to some extent. According to additional analyses, approximately one half of the increase of 3.3 percentage units in R squared was due to the formal learning variables and the other half to the non-formal learning variables. We can say that informal learning (as measured in the PIAAC) is particularly strongly associated with good problem-solving skills, but nevertheless, formal and non-formal learning play some minor role.

When looking at the odds ratios in Table 4, we see that the magnitude of the association between the use of ICT skills at home and having good problem-solving skills stands out from the rest. Compared to the adults who rarely used ICT (reference category), the odds of belonging to level 2 or 3 problem solvers was already twice as large for those showing even some (little) ICT use, and if the individual had a lot of ICT activity, the odds ratio was no less than four. In this respect, no other variable in the model comes close. It is also worth noting that the use of reading or writing skills had fairly small odds ratios compared to ICT use. Participating in non-formal studies had a clear positive association with problem-solving skills in TRE, and the magnitude of this association is notable regardless of the time spent in these studies. However, the role of recent formal studies does not seem very large compared to the others, except if the individual was currently studying or had studied in a regular programme, i.e. actually is or was recently a student.

Table 3

Percentages of Individuals with Sufficient (Level 2 or 3) Problem-Solving Skills in TRE in Subgroups of Various Skills Use

Use of reading skills at home	*n*	*Level 2 or 3 problem-solving skills in TRE (%)*
Very little	5451	18.9
Little	10956	30.6
Moderately	14209	42.2
Much	15414	50.1
Very much	15619	55.0
Use of writing skills at home	*n*	*Level 2 or 3 problem-solving skills in TRE (%)*
Very little	12353	22.4
Little	7261	36.5
Moderately	16037	47.1
Much	12017	51.6
Very much	13983	54.1
Use of numeracy skills at home	*n*	*Level 2 or 3 problem-solving skills in TRE (%)*
Very little	12314	25.4
Little	10116	35.6
Moderately	12081	43.2
Much	12980	52.5
Very much	14160	60.1
Use of ICT skills at home	*n*	*Level 2 or 3 problem-solving skills in TRE (%)*
Very little	10328	16.2
Little	10883	33.3
Moderately	12612	46.3
Much	13623	57.6
Very much	13878	61.3

Table 4

Estimated Logistic Regression Model of Sufficient (Level 2 or 3) Problem-Solving Skills in TRE on Formal, Non-Formal and Informal Learning Activities

Explanatory variable	*Regression coefficient*	*Standard error*	*p value*	*Odds ratio*	*Inverse odds ratio*
Formal studies during the last 12 months					
No formal studies	(reference group)				
Participated formal adult education or training	0.24	0.08	0.003	1.28	0.78
Studied in regular program	0.81	0.09	<0.001	2.25	0.44
Level of formal studies during the last 12 months					
No formal studies or level below ISCED 3	(reference group)				
ISCED 3	–0.28	0.10	0.006	0.76	1.32
ISCED 4	–0.22	0.22	0.316	0.80	1.25
ISCED 5 or ISCED 6	0.28	0.10	0.008	1.32	0.76
Time spent in non-formal studies during the last 12 months					
No non-formal studies or time unknown	(reference group)				
1–2 days	0.55	0.05	<0.001	1.73	0.58
3–5 days	0.86	0.06	<0.001	2.36	0.42

6–10 days	0.90	0.06	<0.001	2.47	0.40
more than 10 days	0.78	0.06	<0.001	2.18	0.46
Use of reading skills at home					
Very little	(reference group)				
Little	0.16	0.08	0.061	1.17	0.85
Moderately	0.33	0.09	<0.001	1.39	0.72
Much	0.34	0.08	<0.001	1.41	0.71
Very much	0.23	0.08	0.006	1.25	0.80
Use of writing skills at home					
Very little	(reference group)				
Little	0.25	0.07	<0.001	1.28	0.78
Moderately	0.43	0.07	<0.001	1.54	0.65
Much	0.40	0.06	<0.001	1.50	0.67
Very much	0.16	0.07	0.026	1.17	0.85
Use of numeracy skills at home					
Very little	(reference group)				
Little	0.24	0.07	<0.001	1.27	0.79
Moderately	0.43	0.06	<0.001	1.54	0.65
Much	0.64	0.06	<0.001	1.91	0.52
Very much	0.78	0.07	0.026	2.18	0.46
Use of ICT skills at home					
Very little	(reference group)				
Little	0.70	0.06	<0.001	2.00	0.50
Moderately	1.04	0.06	<0.001	2.83	0.35
Much	1.39	0.08	<0.001	4.00	0.25
Very much	1.39	0.09	<0.001	4.03	0.25

Discussion and Conclusions

This study attempted to develop a novel understanding of how formal, non-formal, and informal learning are associated with problem-solving skills in TRE. Therefore, we employed the Europe-wide PIAAC data. Our results bring new knowledge of how formal and non-formal activities seem to be associated with problem-solving skills in TRE. Furthermore, our research provides some slightly surprising results with respect to the importance of informal learning.

Our results illustrate that more than half of the 16 to 64 year-old European adults seem to have insufficient problem-solving skills in TRE. Thus, a gap appears to exist between the problem-solving skills needed in the digital era and lifelong learning. Only the two youngest age groups had a majority of people with sufficient problem-solving skills in TRE. Still, even in these youngest groups not less than 46% of respondents showed insufficient skills. In line with previous findings, the skills were related to adults' socio-demographic background factors, namely, age, educational background, and occupation (Hämäläinen et al., 2015). The results showed that younger and more educated adults had better skills. The overall level of problem-

solving skills in TRE was higher among individuals who had been engaged in either formal or non-formal learning, compared to those who had not. Of course, given the cross-sectional nature of the data, future studies are needed regarding the development in TRE through the development of formal, non-formal and informal learning. Interestingly, the association between formal learning and problem-solving skills in TRE proved quite weak. Previously, the focus of lifelong learning was heavily placed on formal learning, such as in the school context where learning is steered by curricula (La Belle, 1982). Therefore, future research is necessary to determine if learning problem-solving in TRE has been sufficiently incorporated into formal education.

An important implication of this study is that our results clearly indicate that informal learning activities are highly associated with sufficient problem-solving skills in TRE. Informal learning activities were measured by the extent various skills were used for free-time activities. Although each type of everyday activities (reading, writing, numeracy, ICT skills) was positively associated with the development of problem-solving skills, The use of ICT skills was distinguished as most influential in this respect: more than 60% of the adults who used them most often also reached level 2 or 3 in problem-solving skills (i.e. the two highest levels which we labelled as *sufficient*). In addition, we found that, compared to the lowest activity level, even low to medium use of ICT for activities showed to be connected for having better skills. Future studies on these informal learning activities are needed to understand their importance, and more specifically, to shed light on how and in which contexts they are used at home, and how these activities are related to problem-solving skills.

This study illustrates that by using the Europe-wide PIAAC data, it is possible to investigate lifelong learning ecologies in a novel way on a general level, e.g. how lifelong learning is manifested within age groups. This kind of knowledge can be applied to guide the research, policies and practices that support learning ecologies in the digital era. Despite its potential, when considering the findings, the following limitations need to be carefully considered. First, the data was collected in the PIAAC large-scale assessment context, and although this allows for a comprehensive view of general adult skills for a large sample, the main focus was not on informal learning. In addition, non-formal learning was somewhat loosely defined. In practice, it could have been anything from a cookery course at a community college to a fencing course organised by a sports club. Second, the variables in the PIAAC data set

measuring formal, non-formal and informal learning activities were not fully comparable. For example, whilst formal learning was only measured with dichotomous (yes/no) variables for participation in various activities and the ISCED level that these activities corresponded to, non-formal learning was practically only measured by the time spent on the learning activities. Of course, the nature of formal learning activities differs somewhat from non-formal learning activities, which may make it impossible to measure them similarly. In addition, in the PIAAC background questionnaire, there were many more questions (and, consequently, more variables) about activities that appeared to be more closely related to informal learning than formal and non-formal learning. All these issues may introduce biases when trying to assess the relative importance of the three kinds of learning activities. Third, as the data is cross-sectional, and the evolution of problem-solving skills cannot be tracked over time. Therefore, future research focussing on longitudinal data is necessary to enhance our understanding of how adults' skills evolve over time, and how this is related to their involvement in formal, non-formal, and informal learning activities. Finally, based on this study, it is impossible to claim that formal, non-formal and informal activities would cause or explain skill differences; or vice versa, that skill differences would explain the distribution across these categories. Instead, we were able to indicate associations between activities and problem-solving skills in TRE. These associations can be used as a starting point for future studies on how adults achieve sufficient problem-solving skills in TRE. Furthermore, we do think that adults need sufficient opportunities to engage in problem-solving in TRE. Therefore the future studies are also needed to develop novel ways to stimulate adults problem-solving skills in TRE for example through offering them design-based learning activities (see Chen & Chiu 2016).

In sum, this study indicates that lifelong learning takes place in different TRE (Barron, 2006; Jackson, 2013) by crossing the boundaries between formal and informal learning (Sharples, 2000). The findings suggest that adults' learning ecologies are a combination of formal, non-formal, and informal learning, of which the latter was most associated with sufficient problem-solving skills in TRE. Furthermore, our results indicate that informal, personalised and self-directed activities may be very meaningful for fruitful lifelong learning in the digital era (see also Fevre et al., 2000; Za et al., 2014). For future, we suggest that informal learning should be studied through interventions and case studies to gather detailed knowledge about how adults' problem-solving skills in TRE can be triggered. Although it is hard to get a

grip on what adults do at home in their free time, this detailed knowledge may be a start for stimulating—or at least creating safe and supportive environments for— informal learning in non-formal and formal settings, as these settings are prone to interventions.

Statements on open data, ethics and conflict of interest

Accordingly, the ethical code of conduct set by the Finnish Advisory Board on Research Integrity was followed (see Finnish Advisory Board on Research Integrity 2012).
Data generated during and/or analyzed during the current study are available in http://www.oecd.org/skills/piaac/publicdataandanalysis/.

There are no potential conflicts of interest in the work.

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