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EQUALITY IN COGNITIVE LEARNING OUTCOMES: THE ROLES OF EDUCATIONAL PRACTICES

Aino Saarinen

ACADEMIC DISSERTATION

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Custos

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Aino Saarinen

**Equality in cognitive learning outcomes:
the roles of educational practices**

Abstract

In the recent years, a decline in Finnish students' learning outcomes has been reported in several investigations, such as in the Programme for International Student Assessment (PISA) and in the Trends in International Mathematics and Science Study (TIMSS). Further, variance in learning outcomes between students coming from different backgrounds has increased in Finland. This dissertation investigated (i) whether self-directed learning practices, use of digital learning materials at school, and participation in early education and care (ECEC) are associated with students' learning outcomes at 15 years of age and (ii) whether these associations are modified by students' background factors.

The participants (N=5660, 5037, and 4634 in Studies I–III) came from the Finnish PISA 2012 and 2015 datasets that constitute a representative sample of the Finnish 15-year-old students. Learning outcomes in reading, mathematical, and scientific literacy and collaborative problem-solving were evaluated with a comprehensive set of standardized tests. The frequency of learning practices (student-oriented, inquiry-based, and teacher-directed practices, and use of digital learning materials at school) were evaluated with questionnaires fulfilled by students. Participation in ECEC was evaluated with age at entry into ECEC. Background factors under investigation included gender, repetition of a grade, truancy behavior at school, family wealth, maternal education, single-parent family, and immigrant status. The data were analyzed with structural equation models that were controlled for age, gender, and parents' socioeconomic status (the index of economic, social, cultural status).

Frequent use of self-directed teaching practices or digital learning materials at school were associated with students' weaker learning outcomes in several knowledge domains. Instead, frequenct teacher-directed practices were related to students' higher learning outcomes. Moreover, frequent use of self-directed teaching practices or digital learning materials had more negative impact on students' learning outcomes in students with (vs. without) risky background. Additionally, participation in ECEC before preschool was not associated with learning outcomes at 15 years of age. This association was not significantly moderated by parental socioeconomic status (as measured with the index of ESCS). At a trend level, the impact of participation in ECEC before preschool was slightly more positive for offspring of parents with high (vs. low) socioeconomic status.

In conclusion, some pedagogical practices within the school system, such as frequent use of self-directed learning practices or digital learning material, were found to increase variance in learning outcomes between students coming from different backgrounds in Finland. No evidence was found that participation in ECEC would be related to learning outcomes at 15 years of age or would increase equality between students coming from different family backgfounds.

Keywords: Early education and care; Digital learning; Self-directedness; Learning outcomes

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Aino Saarinen

Varhaiskasvatuksen ja koulutusstrategioiden yhteys oppimistulosten tasavertaisuuteen

Tiivistelmä

Viime vuosina suomalaisoppilaiden oppimistulosten on havaittu heikentyneen useissa tutkimuksissa, kuten PISA-testeissä (Programme for International Student Assessment) ja TIMMS-testeissä (Trends in International Mathematics and Science Study). Lisäksi oppimistulosten varianssi erilaisista taustoista tulevien oppilaiden välillä on kasvanut Suomessa. Tässä väitöskirjassa selvitettiin, (i) ovatko itseohjautuvuutta edellyttävien menetelmien käyttö, digitaalisten oppimismenetelmien käyttö tai varhaiskasvatukseen osallistuminen yhteydessä oppimistuloksiin 15 vuoden iässä ja (ii) muokkaavatko oppilaiden taustatekijät näitä yhteyksiä.

Tutkimusotos (N=5660, 5037 ja 4634 Tutkimuksissa I–III) koostui Suomen PISA 2012 ja 2015 -aineistoista, jotka muodostavat edustavan otoksen 15-vuotiaista suomalaisoppilaista. Oppimistulokset lukemisessa, matematiikassa, luonnontieteissä ja yhteisöllisessä ongelmanratkaisussa arvioitiin kattavalla ja standardoidulla testipatteristolla. Oppimismenetelmät (oppilaslähtöiset menetelmät, tutkivan oppimisen menetelmät, opettajalähtöiset menetelmät sekä digitaaliset menetelmät) arvioitiin oppilaiden täyttämillä kyselyillä. Varhaiskasvatukseen osallistuminen arvioitiin varhaiskasvatuksen aloitusiän mukaan. Tutkimuksessa tarkastellut oppilaiden taustatekijät sisälsivät sukupuolen, luokalle jäämisen, häiriökäytöksen koulussa, perheen varallisuustason, äidin koulutustason, vanhemman yksinhuoltajuuden sekä maahanmuuttotaustan. Aineistot analysoitiin rakenneyhtälömalleilla, joissa kontrolloitiin ikä, sukupuoli sekä vanhempien sosioekonominen asema (ekonominen, sosiaalinen ja kulturaalinen status).

Itseohjautuvuutta edellyttävien menetelmien käyttö tai digitaalisten menetelmien käyttö koulussa olivat yhteydessä heikompiin oppimistuloksiin useilla osa-alueilla. Opettajalähtöisten menetelmien käyttö oli yhteydessä korkeampiin oppimistuloksiin. Itseohjautuvuutta edellyttävien sekä digitaalisten oppimismenetelmien käytöllä oli erityisen negatiivinen vaikutus oppimistuloksiin niillä oppilailla, joiden taustaan sisältyi riskitekijöitä. Lisäksi havaittiin, että osallistuminen varhaiskasvatukseen ennen esikoulua ei ollut yhteydessä oppimistuloksiin 15 vuoden iässä eikä vanhempien sosioekonominen status merkitsevästi muokannut tätä yhteyttä.

Trenditasolla havaittiin, että varhaiskasvatukseen osallistumisella oli hiukan positiivisempi vaikutus oppimistuloksiin niiden yksilöiden keskuudessa, joiden vanhemmilla oli korkea (verrattuna matalaan) sosioekonominen status.

Tietyt pedagogiset käytännöt koulujärjestelmän sisällä, kuten itseohjautuvuutta edellyttävien tai digitaalisten menetelmien käyttö, näyttävät lisäävän hajontaa oppimistuloksissa: erilaisista taustoista tulevien oppilaiden väliset erot oppimistuloksissa näyttävät kasvavan. Ei löydetty evidenssiä sille, että varhaiskasvatukseen osallistumisen olisi yhteydessä oppimistuloksiin 15 vuoden iässä tai lisäisi tasa-arvoa erilaisista taustoista tulevien oppilaiden välillä.

Avainsanat: Varhaiskasvatus; Digitaalinen oppiminen; Itseohjautuvuus; Oppimistulokset

To all the children
who are required too much self-directedness too early at school

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In addition, I am thankful for the peer-reviewers of the educational journals for giving me comments that opened my eyes. For example, before their comments, I had heard in Finland that evidence is lacking whether specific pedagogical practices are related to learning outcomes. After reviewers' comments, it was a pleasure to realize that there is nothing new in my findings but, in fact, my findings are in full accordance with previous research evidence. I also thank for the international researchers for inspiring discussions that have helped me to understand their concerns related to the Finnish curricular reforms.

At the Department of Psychology, I would like to thank the large number of colleagues who have encouraged me to write this dissertation. I guess that some of those colleagues may not be even aware of their crucial role for promoting this dissertation. I also thank my colleagues for pointing out that this dissertation may not promote my career. Those comments helped me to understand that a doctoral dissertation does not need to promote one's career but, instead, making science can be fun itself and produce inspiration that is worth all the effort.

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In Helsinki, 8.10.2020

Aino Saarinen

CONTENTS

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following publications:

I Saarinen, A., Lipsanen, J., Huotilainen, M., Hintsanen, M., & Keltikangas-Järvinen, L. (2020). The association of student-oriented teaching in mathematics lessons with students' mathematical performance in Finland: Study on the Finnish PISA data. *Electronic Journal of Research in Educational Psychology, 18,* 153–178.

II Saarinen, A., Lipsanen, J., Hintsanen, M., Huotilainen, M., & Keltikangas-Järvinen, L. (2020). The use of digital technologies at school and cognitive learning outcomes: Findings from the Finnish PISA 2015 data. Accepted for publication in *International Journal of Educational Psychology*.

III Saarinen, A., Lipsanen, J., Hintsanen, M., Huotilainen, M., & Keltikangas-Järvinen, L. (2019). The association of early education and care with cognitive learning outcomes at 15 years of age in Finland: Findings from the PISA 2015 data. Published in *Psychology, 10,* 500–520.

ABBREVIATIONS

CFI	The Comparative Fit Index
ECEC	Early childhood education and care
ESCS	The index of economic, social, and cultural status
ICT	Information and communications technology
ILO	The International Labour Organization
ISCO	The International Standard Classification of Occupations
ISCED	The International Standard Classification of Education
NICHD	The National Institute of Child Health and Human Development
OECD	The Organisation for Economic Co-operation and Development
PISA	The Programme for International Student Assessment
RMSEA	The Root Mean Square Error of Approximation
SES	Socioeconomic status
TLI	The Tucker-Lewis Index

1 LITERATURE REVIEW

1.1 POOR SCHOOL PERFORMANCE AND LATER DEVELOPMENT

Poor school achievement is of great societal importance since it composes a major risk for social marginalization later in life. Regarding socioeconomic outcomes, there is evidence that poor school performance predicts lower socioeconomic status and higher risk for unemployment in adulthood (Chen & Kaplan, 2003; Kokko et al, 2003; Li, 2006; Slominski et al., 2011). Poor school performance also predicts a lower likelihood for achievement of a secondary-level education (Berlin et al., 2011) and a higher risk for economic hardship (Forsman et al., 2016).

With regard to physical health, there is evidence that school drop-out predicts elevated risk for long-term sickness and disability in young adulthood (De Ridder et al., 2013). Additionally, poor school achievement predicts risky health behavior in adulthood: for example, smoking (Bryant et al., 2000; Minkkinen et al., 2019), excessive alcohol use and substance dependencies (Berlin et al., 2011; Gauffin et al., 2015; Hayatbakhsh et al., 2011; Huurre et al., 2010; Maynard et al., 2012; Pitkänen et al., 2008), and obesity (Alatupa et al., 2010; Sobol-Goldberg et al., 2016).

Moreover, previous research literature has demonstrated that low school achievements predict weaker mental health. That is, poor school performance predicts conduct problems (Minkkinen et al., 2018a), more frequent stress-related complaints (Modin et al., 2015), psychiatric symptoms such as depression and suicidality (Berlin et al., 2011; Björkenstam et al., 2011; Epstein et al., 2019; Gunnell et al., 2011; Lehtinen et al., 2006; Shochet et al., 2006; Wallin et al., 2019), and antisocial behavior in adulthood (Johnson et al., 2009).

Finally, school disengagement is related to serious delinquency and official offending (Berlin et al., 2011; Henry et al., 2012; Jaggers et al., 2016), violent criminal behavior (Katsiyannis et al., 2013), and incarceration in adulthood (Wolf & Kupchik, 2017). Taken together, school performance is a crucial factor predicting one's later life trajectories and developmental outcomes.

1.2 RISK FACTORS FOR POOR SCHOOL PERFORMANCE

To date, previous research has clearly identified a variety of risk factors for poor school achievements. Here, the review will be focused on such risk factors that have received much discussion in the past decades: truancy behavior at school, repetition of a grade, male gender, immigrant status, risky family structure, low family wealth, and low maternal education.

Truancy behavior at school and repetition of a grade. These are direct indicators of risk for poor school performance. Truancy behavior at school predicts lower grades and lower educational aspirations (Henry, 2007; Henry & Huizinga, 2007) as well as academic disengagement and skipping of classes (Maynard et al., 2012). Further, repetition of a grade and a low grade point average predict higher risk for school drop-out (Bask & Salmela-Aro, 2013; Legleye et al., 2010).

Male gender. Previous research evidence has demonstrated that boys have on average lower school performance than girls in comprehensive school (Buchmann et al., 2008; Marsh & Yeung, 1998; Pomerantz et al., 2002). The gender differences appear to be partially but not fully explained by students' individual characteristics (Spinath et al., 2014). For example, boys (vs. girls) have on average weaker abilities to adapt to school environment, a lower level of verbal intelligence, a lower self-discipline, and lower certain aspects of motivation (Spinath et al., 2014).

Immigrant status. Students with immigration background are reported to have on average lower school grades (Health et al., 2008; Jonsson & Rudolphi, 2010) and weaker academic success (Schmid, 2001). The findings may be partly explained by language difficulties, lower parental support for school work and school routines, and a higher risk for victimization of bullying (Turney & Kao, 2009). Importantly, the PISA 2018 investigators reported that immigrant students had higher risk for under-achievement in Finland than in any other OECD country (OECD, 2018). Further, immigrant adolescents are reported to have more psychosocial problems and externalizing behavior than non-immigrant adolescents (Minkkinen et al., 2018b). In Finland, especially recently immigrated boys may be at risk for school burnout (Salmela-Aro et al., 2018).

Children of **single-parent families** have a higher risk of low academic achievement and school drop-out when compared to children of two-parent families (Amato, 2001; De Lange et al., 2014; Marks, 2006; Pong et al., 2003). These findings may have several explanations. Firstly, children and adolescents of single-parent families may have lower academic aspirations (Garg et al., 2007). Secondly, interparental conflicts may result in children's elevated stress levels that, in turn, interfere with school work (Amato, 2001). Thirdly, children of single-parent families may have weaker material resources and a lower level of parental support for school work (Garg et al., 2007; Marks, 2006).

Low family income and low family wealth are related to offspring's poorer school achievements (Blanden & Gregg, 2004; Hopson & Lee, 2011; Morrissey et al., 2014; Pong & Ju, 2000). Low family income is found to have a causal relationship with children's school achievements (Blanden & Gregg, 2004). In practice, it has been reported that a $1,000 increase in annual family income is related to an increase of 5–6% of a standard deviation in children's academic achievements (Duncan et al., 2011). Further, it has been found that the educational gap between children coming from families with different income levels has widened in the recent decade (Reardon, 2013). This has been noted also in Finland (OECD, 2016). The association of family income with offspring's school performance may be explained by lower school attendance and lower material resources (Morrissey et al., 2014), less positive perceptions of school climate (Hopson & Lee, 2011), and challenges related to single-parenthood (Pong & Ju, 2000).

Low maternal education. There is a great amount of evidence from international studies that low maternal education predicts children's lower grade point average and higher risk for grade repetition in the elementary school and junior high school (Behrman & Rosenzweig, 2002; Carneiro et al., 2013; Gutman et al., 2003). Also, in Finland, parental education is shown to play a crucial role in children's mathematics achievements at 15 years of age (Martins & Veiga, 2010). The association of maternal education with children's school achievements may likely be explained by positive parental attitudes toward school that are transmitted to their children (Davis-Kean, 2005; Hill & Tyson, 2009; Taylor et al., 2004). A second explanation may lie in parental home-based involvement in children's school work that promotes offspring's school performance (Suizzo & Stapleton, 2007).

Taken together, male students, students with truancy behavior at school, students who have repeated a grade, students coming from immigrant or single-parent families, and students with low family wealth or low maternal education are at risk for poor school performance. Hence, when aiming to increase educational equality (i.e. equality in school outcomes between students coming from different family backgrounds), the school performance of these risk groups could particularly be supported.

In the Finnish school system, the comprehensive school was grounded in the 1970s. The comprehensive school starts at 7 years of age and includes the first nine school years, thus providing the basic knowledge for the whole age cohort with a common curriculum. A crucial aim of the comprehensive school has been to provide equal possibilities for education for all students, independently of family background (for a historical review, see e.g. Rantala, 2003). Especially, the aim has been to support children coming from less privileged family backgrounds and provide them possibilities to educational achievements.

1.3 PISA TESTS: RECENT TRENDS IN FINLAND

Decline in the international PISA ranking of the Finnish students. The ranking of the Finnish students across all the countries are shown in Table 1. In the PISA 2003, 2006, and 2009 tests, Finland was ranked among the best countries in all cognitive learning outcomes (Organisation for Economic Co-operation and Development, OECD, 2004, 2006, 2010). This was called even as "the Finnish miracle of PISA" (e.g. Simola, 2005). However, the most recent PISA findings raised concern by demonstrating that the learning outcomes of the Finnish students have declined, particularly in mathematics (OECD, 2016). In the 2018 PISA test, OECD classified Finland to the group of countries with steady decline in learning outcomes (OECD, 2018).

Increased variance in learning outcomes in Finland. Traditionally, one fundamental goal of the Finnish comprehensive school has been to provide equal possibilities for school success for all students, regardless of their family backgrounds (see e.g. Rantala, 2003). In the recent years, however, the variance in the learning outcomes has increased in Finland (OECD, 2016). Especially, the role of socioeconomic family background for learning outcomes has increased in Finland, so that students coming from low-SES families have on average lower skills in mathematics, reading, and science than previously (OECD, 2016). Additionally, immigrant students in Finland have higher risk for under-achieving at school than in any other OECD country (OECD, 2018).

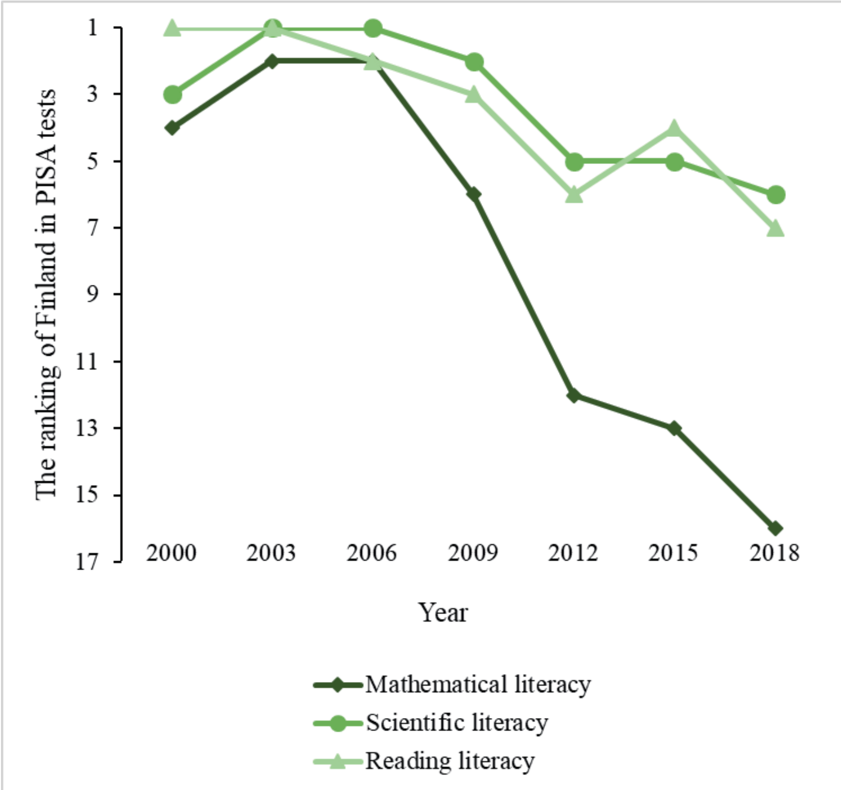


Figure 1. The ranking of Finnish students in the PISA 2000–2015 studies across all the countries participated in PISA.

1.4 THE LEARNING PROCESS IN THE BRAIN

Learning refers to a relatively permanent change in one's knowledge and memory. In this dissertation, the focus is on learning of semantic knowledge (i.e. content knowledge, factual knowledge). Learning is based on neural processes in the brain: it begins when an external stimulus causes a long-term potentiation between neurons that, in turn, results in the formation and stabilization of new synapses (Shahaf & Marom, 2001). Learning of semantic knowledge requires the successful completion of three phases: acquisition, consolidation, and retrieval (Collins, 2007). Commonly, in a learning situation, the phases are in an active interplay with each other (Collins, 2007).

Acquisition occurs in working memory. That is, using working memory, the student identifies the structure of the learning task, selects relevant pieces of information from the learning material, and compares the new information to his/her previous knowledge (Kirschner, 2002; Van Merriënboer & Ayres, 2005). Further, by using working memory, the student organizes the new pieces of information into coherent schemas (Kirschner, 2002; Van Merriënboer & Ayres, 2005; Kirschner et al., 2006). Importantly, however, the working memory has a highly limited capacity, so that overloading working memory substantially reduces the opportunities for efficient learning (Kalyuga et al., 2003; Kirschner, 2002; Mayer & Moreno, 1998). During working memory activities, dorsolateral prefrontal cortex plays a crucial role, especially in attention shifting and concentration (Barbey et al., 2013). There are also differences between different types of working memory activities. For example, the intraparietal sulcus is responsible for spatial working memory (Silk et al., 2010), whereas the superior and middle temporal regions become activated during verbal working memory tasks (Acheson et al., 2011).

The next phase of learning is **consolidation**. During consolidation, the new schemas are transmitted to the long-term memory and assimilated into previous knowledge and wider contexts (Kirschner, 2002; Preston & Eichenbaum, 2013; Van Merriënboer & Ayres, 2005). Long-term memory has a vast capacity. Consolidation is based on various neurochemical processes in the brain such as Hebb's rule (i.e. the neuronal activities influence the synaptic plasticity), long-term potentiation (i.e. a long-lasting increase in the efficiency of a synapse), and CREB protein activation (Collins, 2007; Silva et al., 1998; Yin & Tully, 1996). For successful consolidation, a synchronous functioning of a variety of brain regions is necessary. The brain regions include, for example, the hippocampus, prefrontal cortex, and striatal regions (Collins, 2007; Lorenzini et al., 1999; Preston & Eichenbaum, 2013).

The final phase is **retrieval**. That is, the student retrieves the previously acquired knowledge from the long-term memory. In order to enhance retrieval, the student needs to use various mnemonics (to build coherent and logical schemas, not fragmented pieces of information) and efficient retrieval cues. During the retrieval phase, the involved brain regions include lateral parietal cortex, inferior frontal cortex, and temporal regions (Burianova et al., 2010; Vilber & Rugg, 2008).

Taken together, learning is a multi-phased process that occurs in the brain and is sensitive to disturbations. The likelihood of successful learning process can be strongly increased or reduced by teaching and learning practices and their interplay with the qualities of the student (McClelland et al., 2007). One crucial factor is student's self-directedness. Next, the focus will be on evidence related to the development of self-directedness.

1.5 STUDENTS' SELF-DIRECTEDNESS AND TEACHING PRACTICES

1.5.1 The normative development of self-directedness

Self-directedness is a close concept to self-control, impulse control, self-regulation, self-discipline, and executive functioning (Miyake et al., 2000; Packwood et al., 2011; Strayhorn, 2002a). Self-directedness refers to the following abilities: abilities to regulate one's behavior in accordance with the situational demands; to work in a persistent way toward long-term goals; to control behavioral and emotional impulses; to continue working despite feelings of temporary frustration; to be able to self-monitor one's proceeding toward the goals; and to be able to concentrate and direct attention to the task under work; and to resist allocation of attention to external events that are not relevant for the goal (Cohen & Lieberman, 2010; Miyake et al., 2000; Packwood et al., 2011; Strayhorn, 2002a).

The development of self-directedness is firmly based on maturational processes of the brain. Previous research evidence has shown that the maturation of the prefrontal regions constitutes the basis for the development of self-directedness and related abilities (e.g. self-control, executive functioning, self-regulation) (Arain et al., 2013; Caballero et al., 2016; Luna et al., 2001; Tamnes et al., 2013). The most important regions include the lateral prefrontal cortex (Cohen & Lieberman, 2010; Coutlee & Huettel, 2012; Figner et al., 2010), ventromedial prefrontal cortex (Hare et al., 2009), anteroventral prefrontal cortex (Diekhof & Gruber, 2010), and the rostro-caudal axis in the prefrontal cortex (Badre & D'Esposito, 2007).

There is a great amount of evidence that the prefrontal brain regions belong to the most slowly developing regions in the brain. This is illustrated in Figure 2. It has been shown that the full maturity of the prefrontal regions is not achieved before early adulthood, as measured by cortical thickness and gyrification (Gogtay et al., 2004), brain activity patterns (Luna et al., 2001), synaptic structures (Johnson et al., 2016), neurophysiological responses (Segalowitz & Davies, 2004), myelinization (Paus, 2005), and neurotransmitter systems (Caballero et al., 2016).

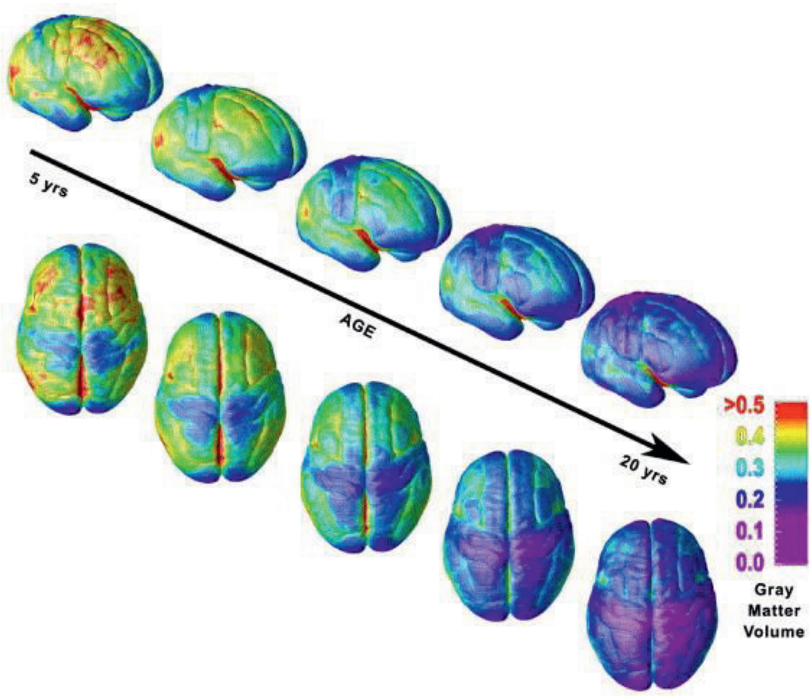
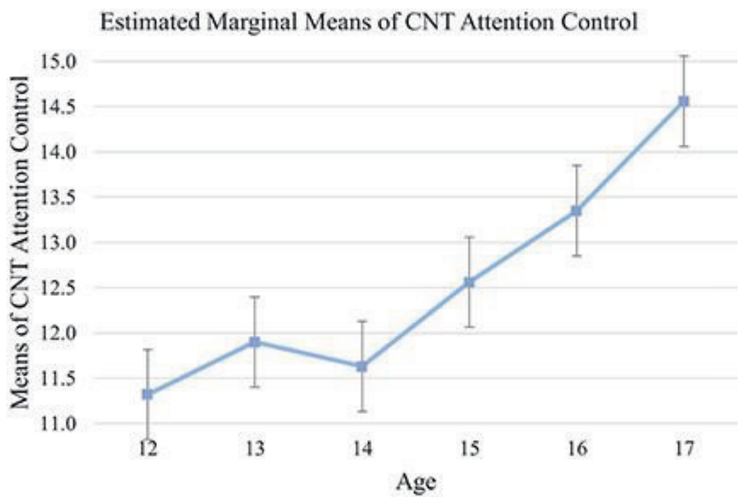


Figure 2. The maturation of cortical regions over age from childhood to early adulthood. Purple and blue colors refer to higher maturity, whereas red, yellow, and green colors indicate lower maturity. Original source: Gogtay, N., Giedd, J. N., Lusk, L., Hayashi, K. M., Greenstein, D., Vaituzis, A. C., ... & Rapoport, J. L. (2004). Dynamic mapping of human cortical development during childhood through early adulthood. *Proceedings of the National Academy of Sciences, 101*, 8174-8179. Copyright (2004) National Academy of Sciences, U.S.A. Republished with the kind permission of the copyright holders.

Also, cognitive and behavioral studies have obtained the slow development of self-directedness over age. Specifically, cognitive control is found to reach the full maturation rate at approximately 20 years of age (Romer et al., 2017). Further, evidence from longitudinal studies has shown that impulsivity (i.e. the disposition to react to environmental stimuli without rational consideration) and novelty seeking (i.e. the tendency to seek for stimuli providing immediate reward and the tendency to become easily bored) stay at a high level even in teenage years and start declining in early adulthood (Harden & Tucker-Drob, 2011). Moreover, there is evidence that different domains of self-directedness (i.e. attention control, cognitive flexibility, and planning ability) develop slowly over age (see Figure 3). It is also necessary to take into consideration that, in some inviduals, these skills may be temporarily slightly regressed e.g. during puberty (Ng-Knight et al., 2016). Further, there are commonly slight differences in the development of various domains of self-directedness-related skills over age so that some domains develop more slowly than others (e.g. Poon, 2018).

(a)



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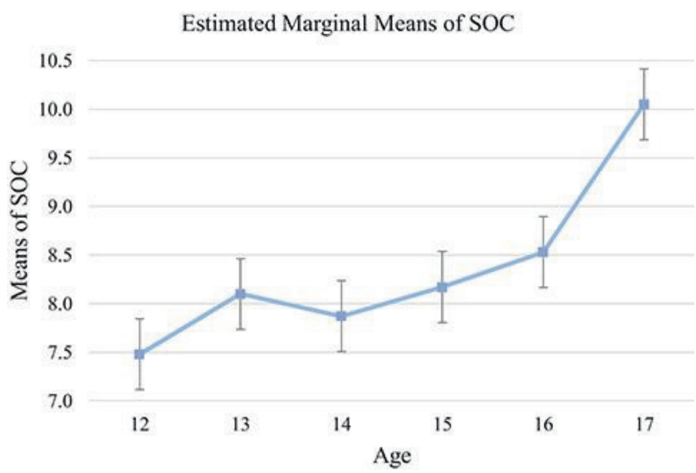

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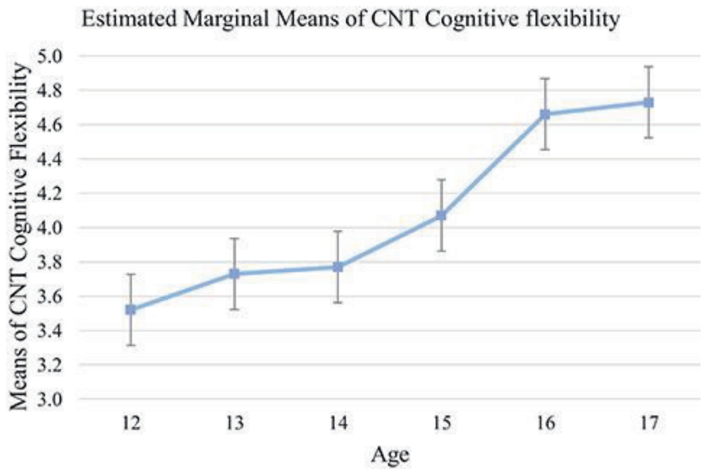


Figure 3. The developmental trajectories of (a) attention control, (b) planning ability, and (c) cognitive flexibility over age. Original source: Poon, K. (2018). Hot and cool executive functions in adolescence: development and contributions to important developmental outcomes. *Frontiers in Psychology, 8*, 2311. Republished with the kind permission of the copyright holders.

1.5.2 The development of self-directedness in risk groups

Importantly, the development of self-directedness is a particularly slow maturational process in children with developmental risk factors. For example, research evidence has shown that there are delays or distortions in the development of the frontal regions in children with neuropsychiatric symptoms: in children with symptoms of attention-deficit-hyperactivity disorder (ADHD) (Almeida et al., 2010; Shaw et al., 2007), in children with autism-spectrum symptomatology (McAlonan et al., 2008), and in children with depressive or anxiety symptoms (Ducharme et al., 2013). The difference in the cortical maturation between children with ADHD and typically developing controls is illustrated in Figure 4.

Additionally, previous evidence has demonstrated that sociodemographic factors are linked to the maturation of the prefrontal cortex. Such factors include low family income (Noble et al., 2015), parental education (Hair et al., 2015; Lawson et al., 2013), low parental socioeconomic status (Jednoróg et al., 2012), and male gender (Lenroot & Giedd, 2010;

Zuo et al., 2010). That is, children coming from these risk groups are found to have delays or other alterations in the development of the prefrontal regions related to self-directedness.

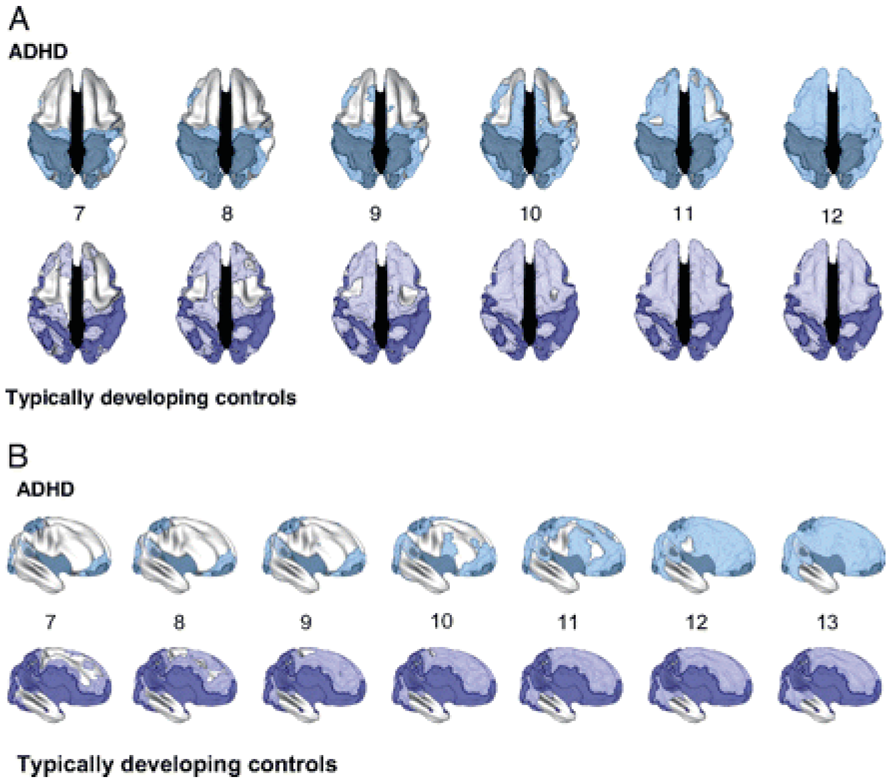


Figure 4. The development of cortical regions separately in children with ADHD and in typically developing controls from two viewpoints (A and B). White color refers to lower maturity of the regions, while blue/purple colors refer to higher maturity. Original source: Shaw, P., Eckstrand, K., Sharp, W., Blumenthal, J., Lerch, J. P., Greenstein, D. E. E. A., ... & Rapoport, J. L. (2007). Attention-deficit/hyperactivity disorder is characterized by a delay in cortical maturation. *Proceedings of the National Academy of Sciences, 104*, 19649–19654. Copyright (2007) National Academy of Sciences, U.S.A. Republished with the kind permission of the copyright holders.

Along with the slower maturation of frontal regions in the brain, children with developmental risk factors are found to have lower self-directedness also in behavioral studies. Regarding neuropsychiatric symptoms, for example, individuals with dyslexia (Gathercole et al., 2006; Reiter et al., 2005), individuals with ADHD symptomatology or learning disorders (Berger et al., 2013; Brown et al., 2009; Nydén et al., 1999; Smith-Spark et al., 2009), individuals with autism-spectrum symptoms (Kerekes et al., 2013), or individuals with depressive symptoms (Holler et al., 2014; Rose & Ebmeier, 2006) are shown to have lower levels of self-directedness and related skills (e.g. self-control, attentional shifting, cognitive control) when compared to typically developing controls. Moreover, individuals with anxiety, depression, or ADHD symptoms have a weaker ability to cope with stress (Leandro & Castillo, 2010; Young, 2005).

Moreover, also sociodemographic factors have influences on the development of self-directedness. Specifically, boys have on average lower levels of self-regulation, self-discipline, and attentional skills (Raffaelli et al., 2005; Spinath et al., 2014; Yamamoto & Imai-Matsumura, 2019). Additionally, students with low school performance have on average lower self-directedness (Mann et al., 2015). Furthermore, children coming from family backgrounds with low socioeconomic status, low family wealth, low family income, or low parental education have on average lower skills in the domains of self-directedness (Ardila et al., 2005; Raver et al., 2013; Rhoades et al., 2011; Sarsour et al., 2011).

1.5.3 Goodness-of-fit between students' self-directedness and pedagogical practices

In school environments, student's self-directedness is strongly linked to the learning process and to the suitability of specific teaching practices in promoting learning outcomes. At school, student's low self-directedness is manifested as a lower ability to regulate one's behavior in accordance to learning goals; a lower ability to control behavioral and emotional impulses in the classroom; a higher tendency to seek for such tasks that arouse immediate reward and enjoyment; a higher tendency to give up at moments of frustration; and a lower ability to self-monitor one's proceeding toward the learning goals.

In general, the pedagogical literature has strongly emphasized the goodness-of-fit between teaching practices and student's self-regulation (McClelland et al., 2007). For example, Gurr's (2001) model states that a combination of highly self-directed student and very strong teacher's guidance may result in a conflict. That is, the student may become frustrated due to excessive guidance and her/his learning process may become disrupted. In contrast, a combination of weakly self-directed student and weak teacher's guidance may lead to "benign neglect" toward the student.

Also, another model (Lee, 2008) recommends that among students with low self-directedness, the teacher should guide the necessary phases toward the learning goal, provide guidance in the selection of appropriate working strategies, and to help with planning the schedule. On the contrary, among students with high self-directedness, the teacher should rather act as a mentor and provide the student more autonomy and freedom (Lee, 2008).

Taken together, different pedagogical practices require a different level of self-directedness from the student and, thus, are suitable to students with different levels of self-directedness. The required degree of student's self-directedness of different pedagogical practices can be illustrated as a continuum, ranging from extremely teacher-directed practices to extremely student-directed practices (see Figure 5). In extremely teacher-directed practices, the teacher defines the learning goals, working strategies, physical spaces for learning, and the order and schedule of learning tasks. In extremely student-oriented practices, in turn, the student sets his/her learning goals, selects a suitable physical space for learning, and makes a plan of the working strategies and schedule. In most cases, teaching practices are likely to lie somewhere in the middle of the continuum.

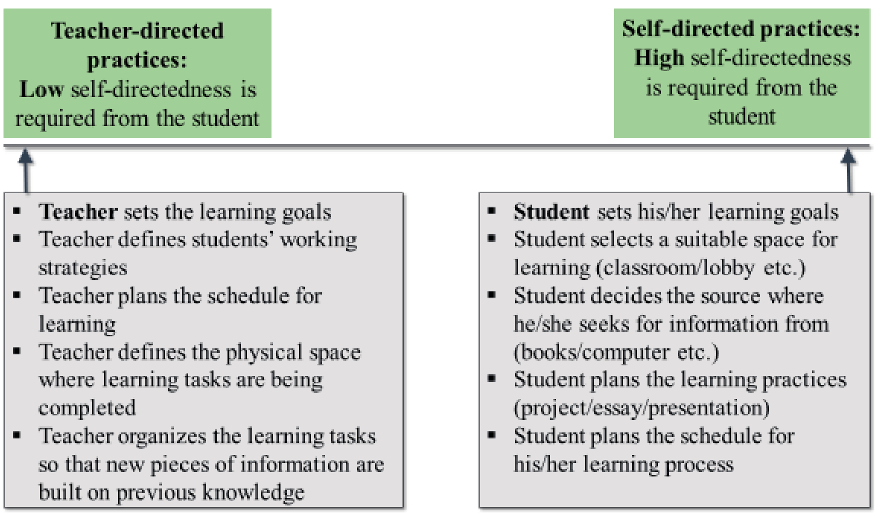


Figure 5. The continuum that presents the required level of self-directedness of students in different teaching practices.

As noted earlier, the development of self-directedness is slow over age and especially slow in students with developmental risk factors. Hence, on the basis of previous neurocognitive studies, teacher can require a higher level of self-directedness from older vs. younger students and from typically developing children vs. children with developmental risk factors. Hence, the frequency of self-directed teaching practices should be adjusted in line with students' age (whether in early education, elementary school, junior high school, or secondary-level education) and students' developmental risk factors (ADHD, learning disorders, depression etc.). That is, young students and students with developmental risk factors need a higher level of teacher's guidance and instruction.

1.5.4 Recent trends in self-directed learning practices

In the recent decades, the school curriculum reforms and educational programs have substantially increased the use of self-directed learning practices in Europe (e.g. Hurmerinta & Vitikka, 2011) and in the US (National Research Council, 1996, 2000, 2012). There have been a variety of arguments for promoting self-directed learning practices. Specifically, self-directed learning practices are suggested to enhance "higher-level thinking skills", "experiential learning" and "deeper learning" (Bransford, Brown, & Cocking, 2000; Furtak & Kunter, 2012; Kim & Davies, 2014; Lipowsky et al., 2009). Moreover, self-directed learning is suggested to result in students' better capacities to formulate their own insights and to apply the new information to various real-life contexts (Kim & Davies, 2014; Lord, 2001). Moreover, it has been suggested that student-oriented teaching is related to students' higher motivation (Guthrie & Wigfield, 2000; Sturm & Bogner, 2008), higher well-being at school (Randler & Bogner, 2006; Schaal & Bogner, 2005), more pleasant feelings during lessons (Lea et al., 2003), higher personal meaningfulness of school subjects (Schaal & Bogner, 2005), and better social skills (Lord, 2001).

Importantly, according to the current national curriculum in Finland (see e.g. the Finnish National Agency for Education, 2016), an important aim of using self-directed learning practices is also to promote students' self-directedness. The development of self-directedness is, however, largely explained by genetic factors. For example, the development of self-control is explained by approximately 80% or more by genetic factors (Beaver et al., 2013; Coyne & Wright, 2014) and the influence of genetics is especially significant between the ages of 12-16 years (Anokhin et al., 2017). Moreover, especially in large classes, it may be challenging for teacher to select such teaching practices that would fit to all the students with varying levels of cognitive skills. This may be especially true in classrooms including students with special needs.

Over the recent decades, a wide variety of self-directed learning methods have been launched one after the other: for example, discovery-based teaching, problem-based learning, inquiry-based learning, student-oriented learning, student-centered learning, and cooperative-learning. In practice, self-directed methods typically include students' individual choices of learning tasks, group work, discussions among students in the classroom, hands-on activities, and interactive games (Caro et al., 2016; Lipowsky et al., 2009; Mayer, 2004; Sturm & Bogner, 2008).

1.5.5 Previous evidence about self-directed learning practices and learning outcomes

Self-directed learning practices in different ages. Overall, the impact of self-directed learning practices on learning outcomes is shown to be crucially different in students with different ages. Specifically, among adults, there is evidence that self-directed learning methods (e.g. problem-based learning or inquiry-based learning) are related to better learning outcomes in a variety of disciplines such as nursing education (Shin & Kim, 2013), in teacher and medical education (Walker & Leary, 2009), and in pharmacy education (Galvao et al., 2014; Zhou et al., 2016).

Among children, in turn, the impact of self-directed methods on learning outcomes is shown to be rather negative or non-significant when compared to traditional learning methods. Specifically, a great number of studies have suggested that frequent use of self-directed teaching practices (e.g. problem-based or inquiry-based learning) are linked with students' weaker learning outcomes in 3-4th graders (Klahr & Nigam, 2004), in 5th-graders (Maxwell et al., 2015), in middle-school students (Wolf & Fraser, 2008), in sevent-graders (Furtak & Kunter, 2012), in 8th graders (Gao et al., 2014), in 9th graders (Schaal & Bogner, 2005), in secondary-school students (Sturm & Bogner, 2008), and in high-school students (Mergendoller et al., 2000). Consequently, a systematic review has concluded that "it is not possible to claim with a high degree of confidence that problem-based learning is indeed more effective in increasing student content knowledge" in high school (Wilder, 2015). Moreover, a meta-analysis indicated that teacher's strong guidance is more effective for younger vs. older students (Lazonder & Harmsen, 2016). Importantly, in Finland, self-directed learning practices have been implemented among comparatively young students, for example, in elementary schools and junior high schools.

The modifying role of students' background factors. A supposition of the recent curricula reforms has been that self-directed learning practices could increase equality in the learning outcomes between students with different cognitive abilities and different socioeconomic backgrounds (Von Secker & Lissitz, 1999). Later on, this assumption has been questioned. For example, it has been stated that students with low school achievements and students coming from low-SES families or minorities may benefit less from self-directed learning practices (Connor, Morrison, & Katch, 2004; Kirschner et al., 2006; Von Secker & Lissitz, 1999; Zohar & Dori, 2003). Additionally, it has been found that self-directed learning practices have differential effects on learning in different student groups (Maxwell et al., 2005), for example, in girls and boys (Wolf & Fraser, 2008). Increased use of self-directed learning practices may also increase the role of parental involvement in school work that, in turn, may increase inequality in students with different educational backgrounds and pedagogical skills of parents. There is also evidence that parental burnout and adolescents' school burnout correlate with each other (Salmela-Aro et al., 2011). Overall, a number of researchers have emphasized that there is a strong need to conduct more research about this topic (e.g. Gao et al., 2014; Klahr & Nigam, 2004; Kyriakides et al., 2013; Walker & Leary, 2009).

Self-directed practices in different phases of learning. Traditionally, self-directed practices (e.g. hands-on activities, interactive games, experimental projects) have been used after the acquisition of basic content knowledge and when aiming to enhance application skills (e.g. Schuh, 2004). In the recent years, there has been a trend to use self-directed learning practices also at the beginning of the learning process. That is, students are supposed to firstly carry out their investigations in various contexts and, in that way, to learn the fundamental concepts of the school discipline (e.g. Schunk, 2008; Terhart, 2003).

To date, research evidence has demonstrated that novices (i.e. students with a low level of content knowledge) may not likely be able to achieve learning goals without teacher-directed instructions (Kirschner et al., 2006; Mayer, 2004). Also, a meta-analysis obtained that the impact of problem-based practices on learning outcomes is weaker at the beginning of studies (vs. at later phases of studies) (Docy et al., 2003). This is because, in novices, self-directed practices may result in cognitive load and the information may not be built coherently on previous knowledge and some key contents may be skipped (Chall, 2000; Kirschner et al., 2006; Mayer, 2004; Moreno, 2004).

1.6 DIGITAL LEARNING MATERIALS AND LEARNING OUTCOMES

1.6.1 Recent promotion of ditical learning materials

In the 2020s, there has been a widespread trend to promote use of digital learning materials (e.g. Clark & Ernst, 2009; Dochy et al., 2015; Prensky, 2010; Skiba & Barton, 2006). For example, it has been demanded that the amount of "digitally supportive schools and digitally confident and supportive teachers" should be promoted (Wastiau et al., 2013).

Along with this, there has been an extensive implementation of digital technologies at schools in Europe and in the US (Becta et al., 2009a,b; Korte & Hüsing, 2006; Law et al., 2008; Office of Educational Technology, 2004), including the use of virtual learning platforms, interactive whiteboards, educational computer games, and mobile learning applications.

Also, in Finland, use of digital learning materials has been vastly promoted. At the beginning of the 2020s, even more than 90% of the Finnish students are estimated to be in highly digitally equipped schools (Wastiau et al., 2013). Thereafter, the Finnish government has implemented a program called "Comprehensive school of the digital era" that aims to modernize the learning environments and to promote utilization of digital learning material (Kaarakainen et al., 2017). Additionally, Helsinki (the capital city of Finland) has launched a program to increase digitalization in the comprehensive school over the years 2016–2019 (School District Office of Helsinki, 2016). The economic investment of the program is 37 000 000€ (School District Office of Helsinki, 2016). Consequently, the economic investments to digital learning methods have been enormous in Finland.

The promotion of digital learning materials has been based on the assumption that the youngest generations who were born at the era of digital media would have fundamentally different learning processes, when compared to previous generations (e.g. Barnes et al., 2007; Prensky, 2010; Sheard & Ahmed, 2007; Skiba & Barton, 2006). These individuals have been called "digital natives" and are suggested to have the ability to "multitask", i.e. process information from multiple sources simultaneously (e.g. Clark & Ernst, 2009; Prensky, 2001). Along with this, it has been stated that "digitalization enables the use of novel pedagogical methods for learning and teaching as well as new ways of working that will essentially increase educational effectivity, productivity, and efficacy" (School District Office of Helsinki, 2016).

1.6.2 Methodological limitations of previous studies

As a review concluded (All et al., 2016), previous research about the influence of digital technologies on learning outcomes has included severe methodological limitations (All et al., 2016). Next, the fodus will be on the most common limitations.

Very high methodological heterogeneity. Drawing any firm conclusions from the previous literature is challenging due to the substantial methodological heterogeneity between single studies. Specifically, there have been a wide range of elements varying between single studies: (1) the age of participants (whether children, adolescents, or adults); (2) the status of participants (whether teachers, students, or fellow students); (3) sample size (ranging from single participants to thousands of participants); (4) the presence/absence of a control group without ICT use; (5) the quality of outcome (whether social skills, motivation, or content knowledge); (6) the quality of sampling methods (whether a random sample or a biased sample of volunteers); (7) learning environments (e.g. whether at school, at home, or in a museum); (8) the type of ICT device that has been used (whether cell phones, laptops, e-dictionaries or other e-books, digital pens, classroom response systems etc.); and (9) the type of ICT application (whether games, interactive videos, e-dictionaries etc.). Since there are a range of varying elements between single studies, the results are not comparable with each other. Further, it is challenging to conclude which of the elements contributed most to the learning outcomes.

Non-representative and non-random samples. In many studies, due to insufficient resources, researchers may not have possibilities to educate participants to use digital technology and various learning applications before the study. Consequently, in several studies, the participants have consisted of a selective sample of volunteers that are likely to be more digitally-interested and digitally-capable individuals than on average (e.g. Bruce-Low et al., 2013). Further, some studies have included a mixed sample of students and teachers (e.g. Liu, 2009) or students who own appropriate device (e.g. mobile phones) (e.g. Basoklu & Akdemir, 2010). Moreover, in some studies, experimental and control groups have differed with regard to crucial background characteristics. For example, in some studies, experimental groups have included students with more advantaged backgrounds and fewer special needs than the control group or in the population on average (Gulek et al., 2005). Consequently, representative population-based studies are strongly needed.

Small sample sizes. In several studies, the sample sizes have been very small. Many studies have included even less than 10 participants in the study groups (Creutzfeldt et al., 2012; Nishikawa & Jaeger, 2011;

Pennala et al., 2014). This mitigates the generalizability of the findings to different student populations. In addition, studies with small samples do not provide possibilities for sensitivity analyses or sufficient statistical power that, in turn, reduces the validity and reliability of the findings.

No control groups without ICT use. Several studies (e.g. Chuang et al., 2009; Dunleavy & Heinecke, 2007; Ebrahimzadeh et al., 2016; Gebru et al., 2012; Hsu, 2017; Hwang & Chang, 2011; Hwang & Wang, 2016; Ketamo, 2003; Levinson et al., 2007; Martin & Ertzberger, 2013; Yang & Wu, 2012) have not included a control group that had not used digital technologies. Further, several studies have compared the effect of different instruction strategies on learning outcomes in digital learning environments (e.g. Erhel & Jamet, 2013), instead of investigating the effect of digital learning environments per se. The lack of appropriate control groups seriously reduces the possibilities to draw conclusions about the effectiveness of ICT use on learning outcomes.

Too many elements that may have contributed to the study results. In several studies, the experimental group has been exposed to a variety of educational changes simultaneously: for example, changes in the amount of ICT use, changes in the learning environment (e.g. going out from the school building), and changes in the instructional style (e.g. using inquiry-based learning instead of teacher's instruction). Moreover, in many studies, the "control group" without ICT use has also received lower-quality teaching practices (e.g. less interaction with the teacher) (Abgatogun, 2012), or lower-quality learning material (e.g. with more unnecessary details that may confuse students) (Lu, 2008), or even with no compensatory learning activities at all (Hayati et al., 2013; Riconscente, 2013). Along with this, it is difficult to conclude whether possible improvements in the experimental group were derived from ICT use or some other varying element in the learning process.

Very sophisticated device or programs with low ecological validity. When investigating the influence of ICT use on learning outcomes, many studies (e.g. Ronimus et al., 2014) have adopted an experimental design where the details of ICT use have been extremely carefully adjusted. For example, some studies have investigated "mobile-device-supported problem-based computational estimation instruction" (Lan et al., 2010), "personalised context-aware ubiquitous learning system" (Chen & Li, 2010), or "a radio frecuency identification supported immersive ubiquitous learning environment" (Liu et al., 2009) that require a wide variety of adjustments before any possibilities for practical implementation.

As a result, the findings may not likely be generalized to practical school environments. It has been emphasized that there are a variety of practical challenges when implementing digital technologies to classroom environments (Balanskat et al., 2006). Further, many teachers may not have sufficient knowledge or education about the use of digital technologies at school (Karakainen et al., 2017). Moreover, there is evidence that most students use their laptops for basic tasks (e.g. writing essays, doing homework, or browsing the Internet), instead of very sophisticated programs (Bebell & O'Dwyer, 2010; Penuel, 2006). Consequently, there has been a concern that the impact of digital learning materials has been investigated with “stylized measurements” that may have a low ecological validity (Jacobsen & Forste, 2011).

Narrow outcome domains. A further limitation has been that several studies used very narrow outcomes without possibilities for broader generalizability. For example, some studies have investigated the effect of digital technologies on learning knowledge about computer concepts (Papastergiou, 2009), learning practical and theoretical computer knowledge (Appel, 2012), learning abilities to evaluate content of on-line texts (Hung et al., 2013), or learning knowledge about sexual coercion (Arnab et al., 2013). Accordingly, it has been emphasized that some effects of ICT use on learning are domain-specific and cannot be generalized to other learning outcomes (Sung et al., 2016). Further, a review concluded that it has remained unclear whether ICT use is efficient on promoting higher-level cognitive processing (Boyle et al., 2016).

Limitations of meta-analyses. Along with the limitations of original studies, also meta-analyses have included limitations. Some meta-analyses or reviews have included original studies without any statistical tests, original studies without control groups, or original studies with only single cases (Bebell & Kay, 2010; (Jang et al., 2016; Sung et al., 2016). Further, one meta-analysis included studies not listed in the reference list, studies without published full-text versions, and also reports and theses that had not been peer-reviewed (Jang et al., 2016).

Consequently, two reviews have concluded that more scientific research is needed about the impact of digital learning material on learning outcomes (All et al., 2016; Wilson et al., 2009).

1.6.3 A summary of previous evidence

Table 1 summarizes the studies that investigated the effect of digital learning materials on cognitive learning outcomes (i.e. changes in content knowledge) and that fulfilled the basic methodological criteria for scientific research: included a control group without ICT use; the control group had roughly similar learning materials without digitality; the sample included at least 10 students/study group; the study investigated the effect of ICT use (but not e.g. the effects of different teacher's instructions while using ICT); and included statistical tests (not qualitative analyses).

There were altogether 14 studies with a negative effect of ICT use on learning outcomes; 17 studies with non-significant or contradictory findings (e.g. a negative effect of ICT use in some analyses, and a non-significant effect in other analyses), and 15 studies with a positive effect of ICT use on learning outcomes. This is in line with a review of Finnish researchers concluding that "no straightforward conclusions about the influences of digital technology use on students' learning can be made: it is not possible to confirm clearly that student learning benefits from the use of digital technologies over extended periods of time" (Harju et al., 2019).

Table 1. A summary of the previous original studies about use of digital learning materials and cognitive learning outcomes.

First author (Publication year)	Sample	Research design	Main results
Ahmed (2013)	161 high school students	The control group performed a heat energy experiment in a science laboratory using a heat energy experiment in a laboratory. The experimental group performed the same experiment using a digital learning application.	The experimental group had higher learning performance in knowledge of science in post-tests and retention tests when compared to the control group.
Basoglu (2010)	60 university students	The experimental group used mobile phones as learning tools and the control group used flash cards as learning tools. Outcome: English vocabulary learning.	The experimental group had higher gains in English vocabulary than the control group.
Brooks (2006)	130 pupils	The experimental group received 10 hours of literacy learning via laptops, and the control group continued with normal literacy learning.	There was not any significant difference in spelling skills between the study groups. The experimental group had weaker learning gains in reading than the control group.

Bruce-Low (2013)	55 university students	The experimental group used a mobile learning device loaded with interactive exercises, while the control group conducted a traditional library exercise. Outcome: sports science.	The experimental group had higher increases in knowledge of sports science when compared to the control group.
Carter (2017)	726 university students	Experimental group 1 used laptops and tablets without teacher's screening; experimental group 2 used laptops and tablets with screening of teacher; and the control group used no digital technologies.	Permitting computers or laptops in the classroom predicted significant reduction in exam scores.
Castellar (2014)	74 second graders	The experimental group used an educational game, and the control group completed a set of math drill exercises on paper (equivalent with regard to quantity and difficulty).	The experimental group had higher arithmetic skills than the control group.
Chen (2009)	69 pupils (aged between 9-11 years)	The experimental group utilized mobile formative assessedment feedback during learning. The control group did not use mobile formative assessment feedback.	There were no significant differences between the study groups in learning achievements.
Chen (2010)	85 univesity students	The experimental group used pocket electronic dictionaries, and the control group used paper dictionaries.	There were no differences between the study groups in the comprehension, production, or retention of vocabulary.

Chen (2011)	77 university students	Experimental group 1 had material printed with QR codes and with scaffolded questions; experimental group 2 had material printed with QR codes but without scaffolded questions; experimental group 3 had material without printed QR codes but with scaffolded questions; and the control group had material without printed QR codes and without the scaffolded questions.	There was not any significant difference between the experimental groups and the control group.
Chen (2019)	204 university students	In Condition 1 the students had a digital game with interactive elements; in Condition 2 the students had a digital game without interactive elements; and in Condition 3 the students a paper-and-pencil game.	Participants who played the digital game with interactive elements had higher scores in learning outcomes than the other groups.
Chiu (2013)	33 seventh graders	The students used either printed dictionaries, pocket electronic dictionaries, or online type-in dictionaries. Outcome: English vocabulary retention.	The use of printed dictionaries promoted learning of English vocabulary more effectively than the use of electronic or online type-in dictionaries.

Delasobera (2010)	117 university students	Simulation group: students received a lecture and 10 simulator cases. Multimedia group: students viewed a video made by the American Heart Association and played a computer game. Reading group: students independently read with an instructor present.	Students in the multimedia group showed higher improvements in a short-term retention test when compared to students in the simulation and reading groups.
Douglas (2012)	316 university students	The study combined observation, survey, and interview data and evaluated the effects of cell phone use on learning.	More frequent in-class phone use was related to significantly lower final grades.
Edwards (2013)	46 sixth graders	Experimental group used online laptop in a supervised classroom with electronic communication only, and the control group utilized traditional face-to-face learning.	There were no differences between the study groups in knowledge of mathematics.
Fried (2008)	137 university students	The students had laptops with wireless networking capabilities. Students were instructed at the beginning of the course that they could use the laptops to take notes if they wanted to.	Laptop use was related to significantly lower learning outcomes of the laptop users and also fellow students.
Gulek (2005)	1344 middle school students	The experimental group participated in a laptop program and used a laptop during the	The experimental group showed significantly higher achievements in learning outcomes than the control group.

		school year, and the control group continued at school without any program.	
Hariri (2004)	86 university students	The experimental group studied anatomy using a second-generation virtual reality surgical simulator, and the control group used images from a textbook.	No significant differences were obtained in the learning outcomes between the study groups.
Hembrooke (2003)	44 university students	The experimental group was allowed to use their laptops during the lecture, and the control group was asked to keep their laptops closed during the lecture.	The experimental group learnt significantly less about the lecture content.
Hsu (2011)	50 tourism students	The experimental group used mobile learning, and the control group used traditional methods. In-Class Group (CG) or Mobile Group (MG).	The experimental group had higher retention of vocabulary and grammar of tourism English.
Huang (2010)	32 pupils in the elementary school	The experimental group used a mobile plant learning system, and the control group used a guidebook.	The experimental group had higher learning scores about planting.

Huang (2012)	166 pupils in the elementary school	The experimental group used an e-book, and the control group used a printed book.	There was no differences in learning gains in oral reading skills between the study groups.
Huizenga (2009)	458 pupils in their first year of secondary education	The experimental group played a mobile history game, and the control group received a regular, project-based lesson series.	The experimental group gained significantly more knowledge about medieval Amsterdam than the control group.
Hwang (2013)	51 sixth graders	The experimental group was guided by a mobile learning system in a temple, and the control group was guided by a human guide.	The experimental group had higher gains in local culture learning than the control group.
Hwang (2016)	40 students from a senior high school	The experimental group used mobile game-based activities, and the control group used traditional learning methods.	The experimental group had higher learning gains in language speaking but not in language listening.
Jacobsen (2011)	1026 university students	The study used time-diary and survey data and explored the use of electronic media on learning outcomes.	Use of electronic media was related to lower first-semester grades.
Kang (2012)	2848 university students	The experimental group used narrative case studies using personal response systemst ("clickers"), and the control group used traditional lecture methods.	The control group had higher learning scores in biology.

Karaman (2011)	44 university students	An instructor presented multiple-choice questions. Students in the experiment group used audience response systems, and students in the control group responded verbally.	The experimental group had higher learning achievements in the first 4 weeks but not at the end of the second 4 weeks. There was not any significant difference in retention scores between the study groups.
Lan (2009)	52 fourth graders	The experimental group used a computer-assisted reciprocal early English reading system, and the control group used paper-based reading system.	The experimental group had higher gains in reading skills than the control group.
Lin (2011)	275 university students	The experimental group utilized clicker-based instruction, and the control group used common instructional methods.	The experimental group performed better in a comprehension test of physics than the control group. There were no differences in a calculation test of physics between the study groups.
Mayer (2009)	139 university students	The experimental group used “clickers” to answer questions during a lecture, and the control group responded to questions without “clickers”.	The experimental group had higher scores on course exams than the control group.

McKenzie (2013)	66 university students	The experimental group used online game informed learning activity, and the control group utilized face-to-face teaching.	The control group had significantly higher knowledge scores than the experimental group.
Mueller (2014)	Three separate studies were conducted among university students (N=67; N=151; and N=109)	The experimental group took notes on laptop during a lecture, and the control group took notes on longhand during a lecture.	The three studies indicated that the experimental group had weaker scores in factual content and conceptual knowledge in immediate and delayed testing when compared to the control group.
Radosevich (2008)	145 university students	The experimental group used a digital student response system throughout a semester, and the control group did not use the digital student response system.	The experimental group performed better on a mid-term exam and on a knowledge-retention test.
Rockinson-Szapkiw (2013)	538 university students	The experimental group used e-textbooks of their mobile devices, and the control group used traditional textbooks.	There were no differences in learning outcomes between the study groups.
Rondon (2013)	29 university students	The experimental group used a computer game-based learning method, and the control group used a traditional learning method.	There was no difference in immediate learning between the study groups. The control group had higher long-term

			knowledge retention than the experimental group.
Sana (2013)	44 university students	All the participants attended a lecture and took notes using their laptops. The experimental group completed a set of non-lecture-related online tasks at any convenient point during the lecture, and the control group did not complete any online tasks.	The experimental group had lower learning outcomes than the control group. Additionally, students who had a direct view to a laptop-using peer had lower learning outcomes (compared to those who did not have a direct view).
Shokri (2014)	40 students (aged between 14-16 years)	The experimental group used video games with teacher's assistance, and the control group played traditional educational games without teacher's assistance.	The experimental group had higher scores in language skills in a post-test and in a delayed post-test.
Thornton (2005)	44 university students	The experimental group received short mini-lessons to their mobile phones, and the control group studied paper-printed learning material.	The experimental group had higher learning scores than the control group.
Wessels (2007)	44 university students	The experimental group interacted with a lecturer with mobile computers in a wireless network, and the control group had conventional lecture meetings.	There were no differences in learning outcomes between the study groups.

Wood (2012)	145 university students	During lectures, the experimental group had digitally-based multi-tasking activities; control group 1 took notes using paper and pencil; control group 2 utilized word-processing note-taking; and control group 3 had natural use of technology.	The group who did not use any types of technologies had significantly higher learning scores than the groups who used some type of technology.
Yang (2012)	44 ninth graders	The experimental group used digital game-based learning, and the control group received traditional instruction.	There was not any differences in academic achievements between the study groups.
Young (2014)	52 fourth graders	The experimental group studied English pronounciation using digital game-based activities and drill practice. The control group used only drill practice.	The experimental group had higher learning scores in immediate English pronunciation than the control group. The control group had higher scores in delayed vocabulary retention test.
Yulianto (2016)	74 university students	Experimental group 1 used e-book; Experimental group 2 used video; Experimental group 3 used a combination of e-book and video; and the control group used traditional face-to-face teaching method.	The control group had higher learning gains that the groups with digital learning methods.

Zhang (2006)	138 university students	Experimental group 1 used e-learning environments with interactive video; Experimental group 2 used e-learning environments withot non-interactive video; Experimental group 3 used e-learning environments without video; and the control group had a traditional classroom environment.	The students in the e-learning environment with interactive video had higher learning scores than the other students. There was no difference between students in e-learning environment without interactive video and students in a traditional classroom environment.
Zhang (2011)	78 students (aged between 18-21 years)	The experimental group studied vocabulary via mobile phone SMS text messages, and the control group studied vocabulary using paper material.	The experimental group had higher immediate learning scores than the control group. There were no difference in retention scores between the study groups.

1.6.4 The modifying roles of students' background factors

Importantly, use of digital technologies includes a certain type of learning ideology. That is, use of digital learning materials belongs to the self-directed learning practices. Specifically, it has been stated that use of digital learning materials is aimed to promote students' greater flexibility, freedom, and autonomy and to reduce the use of teacher-centered learning methods (Downes et al., 2002; Fleischer, 2012). Moreover, in several projects, digital devices are stated to be used as "a sort of reinforcement tool to stimulate motivation and strengthen engagement" and, to a lesser degree, as a tool to promote knowledge or cognitive skills (Frohberg et al., 2009). Additionally, it has been emphasized that digital learning materials enable a more "self-paced and self-directed" style of learning (Sung et al., 2016). Along with this, it has been shown that use of digital learning materials is associated with higher degree of self-regulated learning (Hromalik & Koszalka, 2018).

Accordingly, use of digital learning materials requires quite a high level of self-directedness and other skills from the student. For example, in most cases, an efficient use of digital technologies requires abilities to set one's learning goals, abilities to select appropriate digital applications or device, abilities to select a suitable environment where to use digital technologies (e.g. when using a tablet), and abilities to maintain one's attention in the content of the digital learning material (not merely in the technical use of the device).

To date, there is evidence that students coming from risky backgrounds may not possess the necessary skills for an efficient use of digital learning methods. For example, there is evidence that low-SES children have on average lower levels of executive skills, cognitive control, and working memory capacity (Duncan & Magnuson, 2012; Hackman et al., 2014; Sarsour et al., 2011). Moreover, it appears that digital skills are on average different between children coming from rural and urban regions (Salemink et al., 2017), between students coming from different social or ethnic backgrounds (Volman & van Eck, 2001), and between children coming from high- and low-SES families (Andrews, 2008; Tandon et al., 2012). For example, children coming from disadvantaged (vs. advantaged) backgrounds may have different styles to use digital learning materials: they may use digital technologies in a less goal-oriented way and more impulsive react to the stimuli on the screen of the device (Andrews, 2008; Downes, 2002; Tandon et al., 2012). Further, there are differencse in Facebook use between students with different family SES (Dhir et al., 2017). A Finnish study concluded that "adolescents' ways of engaging in using digital technologies are heterogeneous; a minority of young persons has access to parental or peer support and facilitation that engagement in creative use of digital technologies together with their own motivation and efforts may require" (Hakkarainen et al., 2015). Overall, in line with previous statements (Lee, 2005), promoting the use of digital learning methods may simultaneously increase inequality in learning outcomes between children coming from different backgrounds.

Moreover, there is emerging evidence that several background factors are likely to modify the association between digital learning materials and learning outcomes (Jacobsen & Forste, 2011). For example, the use of digital technologies is found to have different impact on learning outcomes in students with higher vs. lower cognitive abilities (Kalyuga et al., 2003; Paas et al., 2004; Van Merriënboer & Ayres, 2005). Further, in students with poor spatial abilities, learning technologies with a high degree of learner-required control are associated with weaker learning outcomes (Garg et al., 1999; Levinson et al., 2007). Consequently, a concern has been expressed that increased use of learning technologies, which require a high level of self-directedness from the student, is "not effective for people with little previous subject matter knowledge or low metacognitive capabilities" and may increase "the risk of skipping over key educational content" (Levinson et al., 2007). Additionally, two reviews have emphasized that frequent use of digital technologies at school may increase inequalities between students coming from different home backgrounds and socioeconomic circumstances (Lee, 2005; Volman & van Eck, 2001).

1.7 EARLY EDUCATION AND CARE (ECEC) AND LEARNING OUTCOMES

In Finland, there has been active societal debate about children's participation in early education and care (ECEC). Specifically, ECEC is suggested to compensate the scarce resources at home in children coming from disadvantaged families (Salmi, 2012). Additionally, it has been postulated that the possibility to participate in ECEC is a fundamental right that cannot be denied from the child (Rantalaiho, 2009; Repo, 2010) and that ECEC "lays the foundation for success in later life" (Määttä & Uusiautti, 2012). Consequently, it has been demanded that a larger proportion of children should be provided with ECEC in the first years of life, based on the argument that this could increase equality in later school achievements (e.g. Hiilamo et al., 2018; Salmi, 2012). In the recent years, the Finnish government has decided to increase children's participation rate in ECEC (Ministry of Education and Culture, 2016). However, research evidence about the impact of ECEC on children's development has been mostly lacking in Finland.

1.7.1 The short-term vs. long-term influences of ECEC

Previous research literature suggests that participation in early education and care (ECEC) is related to better cognitive achievements *during ECEC and in the first school years*. Specifically, it has been found that participation in ECEC predicts better cognitive performance at 3 years of age (Burchinal et al., 2000), higher language performance at 4.5 years of age (NICHD, 2002b), and better skills in reading and mathematics at school entry (Magnuson et al., 2007). Moreover, more time spent in child care is found to be related to better memory in the first school years (NICHD, 2005) and higher cognitive abilities at 8 years of age (Broberg et al., 1997).

Instead, evidence is scarce and contradictory whether participation in ECEC predicts school achievements *after the first school years*. On one hand, there is evidence that participation in ECEC may predict higher schores in cognitive tests at the ages of 7, 11, 14, and 16 years (Apps et al., 2013; Goodman & Sianesi, 2005). On the other hand, several studies have obtained no association between participation in ECEC and cognitive outcomes after the first years of life. For example, it has been stated that participation in ECEC does not predict better cognitive achievements in the first class (Downer & Pianta, 2006; Magnuson et al., 2007), at sixth grade (Belsky et al., 2007), or in adolescence (Colwell et al., 2001)

Accordingly, a review concluded that participation in ECEC seems to have positive short-term effects but much smaller long-term effects on children's cognitive achievements (Burger, 2010). Further, it has been emphasized that more research is needed whether the impact of ECEC on cognitive outcomes "remain, dissipate, or grow in early adolescence" (NICHD, 2005). In particular, it is necessary to investigate factors that could modify the influence of ECEC on cognitive outcomes and, thus, explain the heterogeneity of the previous findings. One such modifying factor could be child's age at entry into ECEC.

1.7.2 The role of child's age at entry into ECEC

Child's age at entry into ECEC appears to be a crucial factor modifying the impact of ECEC on child's development. That is, there is a great amount of evidence that participation in ECEC in the first three years of life is associated with lower cognitive achievements (than participation in ECEC at the age of 3-6 years) (Gregg et al., 2003; Han et al., 2001; Larson et al., 2015; Loeb et al., 2007; NICHD, 2001; NICHD & Duncan, 2003; Morrissey, 2010; Nomaguchi et al., 2006; Ruhm, 2000). Consequently, a review concluded that the "experimental evidence raises serious questions about concluding that an increased amount of child care is detrimental for children's development, at least in the first 3 years of life" (Love et al., 2003). Also, another review concluded that participation in preschool, but not participation in ECEC at a younger age, has a positive impact on child's cognitive achievements (Burger, 2010).

There are several reasons why child's age at entry may play a crucial role. After the first three years of life, children have increasing capacity to, for example, engage in social interactions (e.g. Neuman, 2011), to express their thoughts and feelings to caretakers (Painter, 1999), to maintain secure attachment to their parents despite daily separations (NICHD, 1997; Waldfogel, 2002), to participate in social role-playing with their peers (Howes, 1994), and to self-regulate one's behavior and consciously process rules (Dowsett & Livesey, 2000; Zelazo et al., 1996). Taken together, the age of three years is commonly regarded as a milestone in child's cognitive and socioemotional development, so that after 3 years of age, the child is likely to have better abilities to adapt to ECEC environments. Consequently, the effect of ECEC on child's later development seems to be dependent on child's age at entry in ECEC.

1.7.3 Family background and susceptibility to quality of ECEC

There are a variety of quality indicators of ECEC that have been emphasized in Finnish discussions and are also mentioned in the Finnish child care legislation: for example, child-adult ratios, child group sizes, stability of caregivers, kindergarten teacher's pedagogical knowledge, pedagogical programs provided for children, stability of caregivers, noise levels, and size of physical spaces (see e.g. Early Childhood Education Legislation, 1973/36; Paananen & Lipponen, 2018).

There is accumulating evidence that children coming from risky family backgrounds are especially susceptible to the quality of ECEC. This has been obtained among children from low-income families (Belsky et al., 2007), children growing up in poverty (Phillips & Lowenstein, 2011), children from minority and single-parent families (NICHD, 2002), and children from socioeconomically advantaged families (Elicker et al., 1999), and children with difficult temperaments (Pluess & Belsky, 2009). Consequently, child's family background may increase child's proneness to the quality of ECEC environments and, in that way, modify the effect of ECEC with child's cognitive outcomes. Next, special attention will be paid on five elements that are related to the quality of ECEC and that may influence the effect of ECEC on cognitive outcomes: size of child groups, stability of caregivers, children's socioemotional development, and physiological alterations.

High child-adult ratios and large child groups. To date, it is widely known that high child-adult ratios and large child groups are linked to lower quality of caregiving (NICHD, 2002), caregivers' less supportive and respectful behavior toward the children (De Schipper et al., 2006), less frequent monitoring of children's emotional needs (Ahnert et al., 2006). Further, high child-adult ratios and large child groups are associated with less favorable development of children (Sagi et al., 2002), higher amount of children's externalizing behavior (McCartney et al. 2010), children's lower language skills (Burchinal et al., 2003), and children's lower social status at school entry (Morrissey, 2010). Of special importance are the findings demonstrating that large peer groups are especially detrimental to young children and children from adverse family backgrounds (e.g. low maternal sensitivity) (De Schipper et al., 2006; NICHD, 2000; Sagi et al., 2002).

Instability of caregivers. There is a large amount of evidence showing that instability of caregivers in ECEC environments is detrimental for children's development. Instability of caregivers is shown to predict children's lower well-being, challenges in coping with stress, and more frequent problem behavior (De Schipper et al., 2004, 2004b; NICHD, 1998; Ruprecht et al., 2016). Moreover, instability of caregivers is associated with children's insecure attachment with caregivers (Ahnert et al., 2006). Importantly, very young children and children with difficult temperaments are especially prone to the adverse influences of caregiver instability (De Schipper et al., 2004, 2004b).

It is also important to take into consideration that, in Finland, there have been societal changes that may have increased child-adult ratios and instability of caregivers. In particular, along with a trend of marketization of education (see e.g. Brunila, 2011), the propotion of private ECEC companies appears to have increased that, in turn, may have resulted in a stronger need for reducing salary costs. Even though the Finnish childcare legislation determines child-adult ratios in basic situations, there are a variety of exceptions where the child-adult ratios may be higher than is recommended in the legislation.

Children's socioemotional development. There is firm evidence that participation in ECEC is linked with children's adverse socioemotional development. For example, more time spent in early care predicts externalizing problems and conflicts with adults (Network, 2003), externalizing behavior (NICHD, 2001, 2007), behavior problems and lower self-control (Magnuson et al., 2007; NICHD, 1998, 2016), less harmonious parent-child relations and elevated levels of aggression and non-compliance (Belsky, 2001), lower social competence and poorer social skills (NICHD, 1998, 2016), more teacher-reported externalizing problems in childhood (Belsky et al., 2007). Importantly, the impact of ECEC on socioemotional development is found to endure into adolescence. For example, higher number of hours spent in ECEC predicts higher risk taking and impulsivity at 15 years of age (Vandell et al., 2010). Moreover, the influence of ECEC on children's socioemotional development are found to remain after controlling for ECEC quality (Phillips & Lowenstein, 2011). Further, it has been emphasized that children's socioemotional problems may hinder some of the positive effects of ECEC on cognitive outcomes (Neidel & Waldfogel, 2010).

When participating in ECEC, children from risky backgrounds such as single-parent families or low-income families are found to exhibit a particularly high level of socioemotional challenges (i.e. lower prosociality, less responsive behavior, more conflicts in social relationships) (e.g. Elicker et al., 1999; NICHD, 2002)

Physiological alterations. To date, there is accumulating evidence that participation in ECEC is related to physiological indicators of experienced stress. For example, participation in ECEC is known to predict elevated cortisol levels in childhood and teenage years (Geoffroy et al., 2006; Gunnar et al., 2010; Roisman et al., 2009; Vermeer et al., 2006; Watamura et al., 2009). The increase in cortisol levels in ECEC environments has been demonstrated also in Finland (Hotulainen et al., 2014; Sajaniemi et al., 2014). The fluctuation of cortisol levels is also found to remain quite stable within a semester (Hotulainen et al., 2014). Moreover, it has been found that participation in center-based care predicts increased viral infections (Copenhaver et al., 2004; Fairchok et al., 2010) and elevated adrenaline levels in childhood (Lundberg, 1983).

Importantly, children coming from risk groups are found to be especially prone to elevated physiological stress levels in ECEC environments. For example, children with immature social skills and children with difficult temperaments, and children with insecure attachments exhibit elevated cortisol levels in ECEC (Ahnert et al., 2004; Dettling et al., 1999; Geoffroy et al., 2006; Groeneveld et al., 2012). Moreover, children's elevated physiological stress levels are especially common in low-quality ECEC environments including, for example, large group sizes and smaller physical spaces (Geoffroy et al., 2006; Legendre, 2003; Sims et al., 2006).

Taken together, child's family background may increase child's susceptibility to the quality of ECEC and, thus, modify the association of ECEC with child's cognitive outcomes.

1.7.4 The modifying role of socioeconomic background: current evidence

A great amount of research has been conducted to investigate whether family background modifies the impact of ECEC on child's psychological development. Of the research evidence, a large proportion consists of intervention studies where children with disadvantaged home environments are provided with participation in ECEC. There are, however, several methodological limitations in those intervention studies. Specifically, most studies have not included any control group with home care; or included school-aged children (not children in ECEC); or included children with extremely disadvantaged circumstances (e.g. not access to food, apartment, or health care) that reduces the generalizability of the findings to Western countries (see e.g. Burchinal et al., 2000; Burger, 2010; Campbell et al., 2005; Côté et al., 2007; Love et al., 2005).

Consequently, when aiming to investigate the modifying role of family background on children's development, it is necessary to focus on observational studies with random sampling and appropriate control groups. To date, evidence has been very inconclusive. Some studies have found evidence for some kind of "compensatory" impact of ECEC on psychological development among children coming from risky backgrounds. For example, it has been found that, in children with risky (vs. favorable) backgrounds, participation in ECEC has more positive effect on reading and math skills (Magnuson et al., 2007; Melhuish et al., 2008; Votruba-Drzal et al., 2013), cognitive test scores (Apps et al., 2013), and language skills (Geoffroy et al., 2007; Peisner-Feinberg et al., 2001).

Other studies, in turn, have not found any evidence for "compensatory" effects of ECEC on psychological development among children with less privileged backgrounds. For example, there is evidence that family background did not modify the impact of ECEC on language skills, math skills, or memory skills (NICHD, 2002c, 2005; Ruzek et al., 2014), externalizing behavior (Vandell et al., 2010), behavior problems, or self-control (NICHD, 1998, 2005, 2002c; Votruba-Drzal et al., 2010). Importantly, some findings have indicated that participation in ECEC (vs. home care) is more detrimental for children coming from low-income families (e.g. NICHD, 2002b). Overall, a review indicated that participation in ECEC cannot compensate disadvantaged home environments (Burger, 2010).

2 AIMS OF THE PRESENT STUDY

In the recent years, there has been a decline in the international PISA ranking of the Finnish students in cognitive learning outcomes. Moreover, the inequality in cognitive learning outcomes between Finnish students coming from different backgrounds has increased. The aim of this dissertation was to investigate whether some factors inside the Finnish educational system could be associated (1) with the level of students' cognitive learning outcomes and (2) with the equality in cognitive learning outcomes between students coming from different backgrounds. The focus was on three factors that have been actively discussed and economically enhanced in Finland in the recent years: participation in early education and care, use of digital technologies, and student-oriented learning strategies. Three separate studies were conducted. The study design is illustrated in Figure 6. The research aims were as follows:

Study I. The aim of Study I was to investigate

(i) whether the frequency of student-oriented teaching strategies during mathematics and science lessons is associated with students' learning outcomes in the Finnish PISA 2012 and 2015 data.

(ii) whether this association is modified by students' risky background characteristics. That is, whether student-oriented teaching could influence equality in cognitive learning outcomes between students coming from different family backgrounds.

Study II. The aim of Study II was to investigate

(i) whether the frequency of using digital technologies at school is associated with cognitive learning outcomes in the Finnish PISA 2015 data (i.e. reading literacy, mathematical literacy, scientific literacy, and collaborative problem-solving).

(ii) whether this association is modified by risky background factors, availability of digital technologies at school, or student's competence in using digital technologies. That is, whether the use of digital technologies could influence the equality in cognitive learning outcomes between students (a) with different family backgrounds, (b) with different competencies in using digital technologies, or (c) with different availability of digital technologies.

Study III. The aim of Study III was to investigate

(i) whether participation in early education and care is associated with cognitive learning outcomes in the Finnish PISA 2015 data (i.e. reading literacy, mathematical literacy, scientific literacy, and collaborative problem-solving).

(ii) whether this association is modified by parental socioeconomic status. That is, whether participation in early education and care could influence the equality in the learning outcomes between students coming from different socioeconomic family backgrounds.

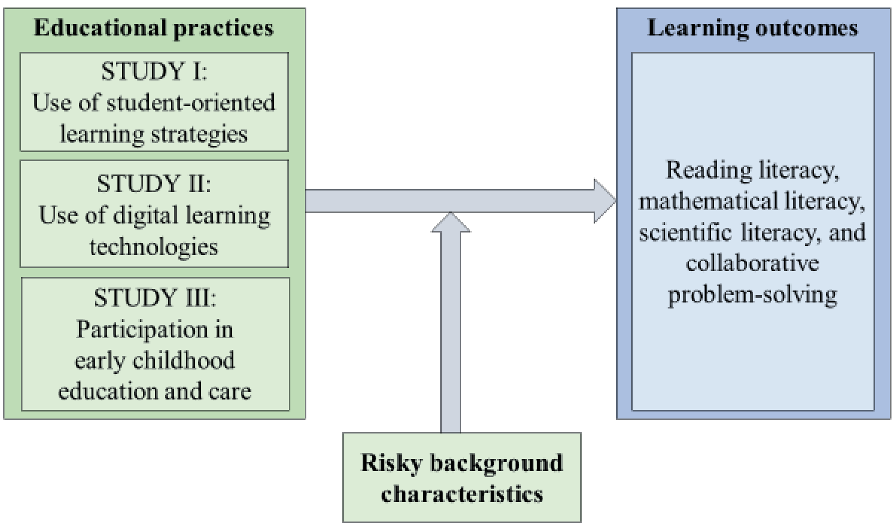


Figure 6. The study design.

3 METHODS

3.1 PARTICIPANTS

All participants of this dissertation were selected from the Finnish PISA (Programme for International Student Assessment) data. The PISA is an international study that investigates students' cognitive learning outcomes across the OECD (Organization for Economic Co-operation and Development) countries. The PISA studies have been organized from the year 1999 onwards. In this dissertation, the 2012 PISA data (Study I) and the 2015 PISA data (Studies I–III) were used.

In the PISA 2012 and 2015 studies, the samples were selected via two phases. Firstly, in each country, the investigators selected at least 150 national schools that were teaching students within the target age group (aged between 15 years and 3 months and 16 years and 2 months; and at grade 7 or higher). In Finland, the registers of learning institutes of Statistics Finland did not include dates of birth (Nissinen, Rautopuro & Puhakka, 2018). Hence, the target group primarily included ninth-graders of Finland (Nissinen, Rautopuro & Puhakka, 2018). In Finland, this desired target population was representative of the Finnish population of 15-year-old students with regard to the most important sociodemographic factors. Secondly, from each included Finnish school, on average 35 students (PISA 2012) or 42 students (PISA 2015) within the target age group were randomly selected. The students were not selected as entire classes but as single students from different classes (Nissinen, Rautopuro, Puhakka, 2018).

At school-level, the primary reasons for exclusion were as follows: schools that were geographically unreachable; schools where the organization of the PISA assessment was not possible by practical reasons; and schools that included students only from a specific population (e.g. schools for the blind). Further, schools where the primary language was not Finnish or Swedish were excluded but this may not have caused any significant bias (Nissinen, Rautopuro & Puhakka, 2018). At student-level, the main exclusion criterion was limited language proficiency or an intellectual or functional disability (assessed by a professional). In Finland, most common reasons for dropping out from the sample were absence during the test day and technical problems with computers at school (Nissinen, Rautopuro & Puhakka, 2018).

The general design and sampling of the international PISA 2012 and 2015 studies are described with more detail elsewhere (OECD, 2014, 2017a). The sampling methods of the Finnish PISA datasets have been described thoroughly elsewhere (see e.g. Nissinen, Rautopuro & Puhakka, 2018).

The final Finnish sample included altogether 5882 students in PISA 2015 test and 8829 students in PISA 2012. In this dissertation, all the students with complete data on the study variables were included in the analyses. Due to this, the final sample size varied between Studies I–III. There were 5660, 5037, and 4634 participants in Study I, Study II, and Study III, respectively. The research design and study variables of Studies I–III are shown in Table 2. The means, frequencies, and standard deviations of the study variables are presented in Table 3.

Table 2. The research design, study variables, and main statistical method used in Studies I–III.

	Study I	Study II	Study III
Research design	Cross-sectional	Cross-sectional	Cross-sectional
Independent variables	Student-oriented teaching strategy Inquiry-based teaching strategy Background characteristics (i.e. immigration status, family structure, truancy behavior at school, family wealth, maternal education)	Use of ICT at school Students' competence in ICT use Availability of ICT at school Background characteristics (i.e. immigration status, repetition of a grade, family wealth, maternal education)	Early education and care The index of ESCS
Dependent variables	Mathematical literacy Scientific literacy	Mathematical literacy Scientific literacy Reading literacy Collaborative problem-solving	Mathematical literacy Scientific literacy Reading literacy Collaborative problem-solving
Control variables	Age Gender The index of ESCS Teacher-directed instruction	Age Gender The index of ESCS	Age Gender The index of ESCS
Main statistical method	Structural equation model	Structural equation model	Structural equation model

Table 3. The means, standard deviations (SD), frequencies, and ranges of the variables in Studies I–III.

	Study I (*N*=5660)		Study II (*N*=5037)		Study III (*N*=4634)	
	Mean / Frequency (%)	SD	Mean / Frequency (%)	SD	Mean / Frequency (%)	SD
Age	15.71	0.28	15.72	0.28	15.73	0.28
Gender (Female)	2842 (50.2)		2524 (50.1)		2365 (51.0)	
ECEC						
Starting age at ECEC					3.91	1.49
Preschool at 6 years of age only					852 (18.4)	
Preschool at 6 years of age and ECEC started in 3–5 years of age					2883 (62.2)	
Preschool at 6 years of age and ECEC started before 3 years of age					899 (19.4)	
The index of ESCS	0.36	0.83	0.28	0.74	0.29	0.73
Risky background characteristics						
Low maternal education	468 (8.3)		312 (6.2)			
Low family wealth	1446 (25.5)		1107 (20.0)			
Immigrant status	791 (14.0)		161 (3.2)			
Repetition of a grade			119 (2.4)			
Truancy behavior at school	2986 (52.8)					
Risky family structure	911 (16.1)					
Cumulative risk score	1.62	1.10	0.81	0.75		
Classroom characteristics						

Use of ICT at school			0.10	0.72		
Availability of ICT at school			6.92	2.09		
Students' ICT competence			-0.08	0.90		
Student-oriented teaching strategy	0.018	0.84				
Inquiry-based teaching strategy	-0.31	0.86				
Teacher-directed instruction	-0.062	0.92				
Cognitive learning outcomes[1]						
Mathematical literacy	511.49	85.07	518.34	73.09	518.02	72.69
Scientific literacy	531.57	91.93	539.97	88.68	538.19	88.72
Reading literacy			537.12	82.60	535.66	83.10
Collaborative problem-solving			542.21	87.24	541.20	86.96

[1] The mean of the plausible values 1–10. ECEC=Early childhood education and care

3.2 MEASURES

3.2.1 Cognitive learning outcomes (Studies I–III)

In the PISA 2012 and 2015 data, the measurement of cognitive learning outcomes (scientific literacy, reading literacy, mathematical literacy, and collaborative problem-solving) included altogether 810 minutes of test items. The students performed various combinations of the test items. For each student, a two-hour-long test pattern was selected including four pieces of 30-minute clusters: two clusters in the field of scientific literacy and the other clusters in the fields of reading literacy, mathematical literacy, and collaborative problem-solving. All the items were rated with one of the following rating types: closed constructed-response (e.g. writing a single number), open constructed-response (a slightly longer written response), or multiple choice-response (selecting one or more responses from a response set). In the PISA 2015 data, all the items were performed with computer-based tests. The measurement designs of the cognitive learning outcomes in the PISA 2012 and 2015 datasets are described with more detail elsewhere (OECD, 2013, 2017b). In the PISA 2012 and 2015 data, the theoretical basis of cognitive learning outcomes was mostly similar.

The test of scientific literacy measured students' abilities (i) to explain phenomena in a scientific way (in the fields of biology, physics, chemistry, and space sciences), (ii) to assess and design necessary steps in scientific investigations (e.g. to define dependent and independent variables, control variables, and methods to decrease measurement error), and (iii) to interpret and reflect evidence scientifically (to differentiate between scientific hypotheses, observations, and facts).

The test of reading literacy assessed the students' capacity to understand, interpret, integrate, and reflect the content of different types of texts. Hence, the test of reading literacy aimed not to measure the most basic reading skills. The text types consisted of continuous texts (e.g. chapters, books), non-continuous text materials (e.g. lists, tables, graphs, advertisements, indexes) and combinations between them. The texts were placed in personal, occupational, educational, and public contexts so that the items measured students' abilities to apply their reading skills in various of daily events.

The test of mathematical literacy referred to students' abilities (i) to formulate contextualized problems into mathematical form, (ii) to employ necessary mathematical computations to solve the problems that have been formulated mathematically (e.g. mental calculation, spatial visualization, modeling mathematical change with appropriate functions), and

(iii) to interpret the mathematical results (e.g. to apply the solutions in various every-day contexts), to evaluate the reasonableness of the results, and to acknowledge the uncertainty of measurements.

The test of collaborative problem-solving measured students' abilities (i) to establish and maintain shared understanding about the task with others, (ii) to take the necessary collaborative steps to solve the problem, and (iii) to create and maintain collaborative organization (so that each group member's knowledge could be utilized). Collaborative problem-solving was evaluated with computer-based items where each student was collaborating with computer agents.

3.2.2 Pedagogical practices at school (Study I)

Teaching strategies at school were evaluated on the basis of the triachic model of instructional quality (OECD, 2013). The model includes three factors that have shown cross-cultural validity: (i) structuring practices (i.e. teacher-directed instruction); (ii) student-oriented practices; and (iii) enhanced activities. In the PISA 2012 study, the two latter factors were combined into one factor referring to student-oriented teaching strategies (OECD, 2013).

The index of student-oriented learning practices was assessed with a 4-item questionnaire filled by the students. The items were as follows: in mathematics lessons, how often the teacher (i) assigns projects that require at least one week to complete; (ii) has students work in small groups to come up with a joint solution to a problem or task; (iii) the teacher gives different work to classmates who have difficulties learning and/or to those who can advance faster; and (iv) the teacher asks students to help plan classroom activities or topics. The statements were rated with a 4-point scale ranging from 1 (every lesson) to 4 (never or hardly ever). The index of student-oriented teaching was scaled so that a higher value of the index referred to more frequent student-oriented teaching practices.

The index of teacher-directed instruction was assessed with a 4-item questionnaire rated by the students. The items measured how often the teacher in mathematics lessons (i) sets clear goals for student learning; (ii) the teacher asks students to present their thinking or reasoning at some length; (iii) the teacher asks questions to check whether students understood what was taught; and (iv) the teacher tells students what they have to learn. The items were rated with a 4-point scale ranging from 1 (every lesson) to 4 (never or hardly ever). The index of teacher-directed instruction was scaled so that a higher value of the index referred to more frequent teacher-directed instruction.

The index of inquiry-based learning practices. As additional analysis, also the index inquiry-based learning in the Finnish PISA 2015 data was used. Inquiry-based learning practices were evaluated with a 9-item questionnaire fulfilled by the students (OECD, 2016). The items measured the frequency of the following practices in science lessons: (i) "Students are given opportunities to explain their ideas"; (ii) "Students spend time in the laboratory doing practical experiments"; (iii) "Students are required to argue about science questions"; (iv) "Students are asked to draw conclusions from an experiment they have conducted"; (v) "The teacher explains how a science idea can be applied to a number of different phenomena"; (vi) "Students are allowed to design their own experiments"; (vii) "There is a class debate about investigations"; (viii) "The teacher clearly explains the relevance of science concepts to our lives"; and (ix) "Students are asked to do an investigation to test ideas". The items were rated with a 4-point scale (1=never or hardly ever; 4=in all lessons) (OECD, 2016). The index of inquiry-based learning practices was scaled so that a higher value of the index referred to more frequent inquiry-based practices.

3.2.3 ICT indices at school (Study II)

The index of ICT (information and communications technology) use at school was evaluated with a 9-item questionnaire filled by the students. The items evaluated how often the students used digital devices for the following activities: (i) "at school"; (ii) "using email at school"; (iii) "browsing the Internet for schoolwork"; (iv) "downloading, uploading or browsing material from the school's website"; (v) "posting [their] work on the school's website"; (vi) "playing simulations at school"; (vii) "practicing and drilling, such as for foreign language learning or mathematics"; (viii) "doing homework on a school computer"; and (ix) "using school computers for group work and communication with other students". The items were rated with a 5-point scale ranging from 1 (never or hardly ever) to 5 (every day). A higher value of the index of ICT use referred to more frequent use of ICT at school.

The index of ICT availability at school was evaluated with a 10-item questionnaire filled by the students. The questions assessed whether the following digital devices were available at school: (i) desktop computer; (ii) portable laptop or notebook; (iii) tablet computer; (iv) internet connected school computers; (v) internet connection via wireless network; (vi) storage space for school-related data; (vii) USB (memory) stick; (viii) e-book reader; (ix) data projector; or (x) interactive whiteboard. The items were answered with a 3-point scale (1="Yes, and I use it"; 2="Yes, but I do not use it"; 3="No"). The total score of the questionnaire was scaled so that a higher value referred to higher ICT availability of the school.

The index of students' perceived ICT competence was assessed with a 5-item questionnaire rated by the students. The items were as follows: (i) "I feel comfortable using digital devices that I am less familiar with"; (ii) "If my friends and relatives want to buy new digital devices or applications, I can give them advice"; (iii) "I feel comfortable using my digital devices at home"; (iv) "When I come across problems with digital devices, I think I can solve them"; and (v) "If my friends and relatives have a problem with digital devices, I can help them". The items were rated with a 5-point scale ranging from 1 (strongly disagree) to 5 (strongly agree). The total score of the items was scaled so that a higher value indicated a higher perceived ICT competence.

3.2.4 Early education and care (Study III)

Students' participation in early education and care (ECEC) (ISCED=0) was assessed with questionnaires filled by students. Students were asked about (1) their child's age at entry into ECEC (in years) and (2) the duration of ECEC (in years). In this study, students were classified into three categories with regard to their participation in ECEC: (1) ECEC at 6 years of age (i.e. preschool); (2) preschool at 6 years of age and ECEC started at 3–5 years of age, and (3) preschool at 6 years of age and ECEC started before 3 years of age. The cut-off age of 3 years has been used also previously (e.g. Mol et al., 2008; Snow et al., 2007). Students who had received ECEC at 7 years of age or older were excluded from the analyses.

In Finland, children start a one-year-long preschool at the age of 6 years. Attendance to preschool is compulsive in Finland. The comprehensive school (including the first 9 school years) starts at the age of 7 years. There is the same curriculum for the whole age cohort in the Finnish comprehensive school. In Finland, kindergarten teachers are educated in university faculties. There must be at least one certified kindergarten teacher in each child group in day-care centers (Early Childhood Education Legislation, 1973/36). Further, there are allowed to be at most 12 children below 3 years in a child group (max 4 children per caretaker) and at most 24 children aged between 3–6 years in a child group (max 8 children per caretaker) in the day-care centers. There are also legal guidelines for room temperature, the noise level of electrical devices, and pedagogical and learning goals in day-care centers. A more detailed description of the Finnish legislation of ECEC is available elsewhere (see Early Childhood Education Legislation, 1973/36).

3.2.5 The index of economic, social, and cultural status (Studies I–III)

The PISA 2012 data. The index of economic, social, and cultural status (ESCS) was evaluated on the basis of questionnaires filled by students. The index of ESCS included of three factors: (1) the highest parental occupation, (2) the highest parental education, and (3) home possessions. Parental occupational status was classified in accord with the ISCO codes (ILO, 2007) and then translated into an international socioeconomic index of occupational status (Ganzeboom, 2010). Parental education was first classified on the basis of ISCED (OECD, 1999), ranging from 0 (no education) to 6 (theoretically oriented tertiary education or post-graduate education). Next, parental educational level was recoded into an estimated number of educational years (for example, in Finland, ISCED level 1=6 educational years; or ISCED level 5=14.5 educational years). In the index of ESCS, the highest parental education referred to the highest number of parental educational years between the parents. Home possessions included four factors: (i) the number of books at home, (ii) family wealth (electronic devices, room space, and cars at home), (iii) cultural possessions of the family (classical literature, books of poetry, works of art at home); and (iv) educational resources of the family (e.g. a desk, quiet place, and computer for studying at home). The statistical estimation of the index of ESCS in the PISA 2012 data is described more precisely elsewhere (OECD, 2014).

The PISA 2015 data. The index of ESCS included three factors: (1) the highest parental education, (2) the highest parental occupation, and (3) family wealth. Parental education was rated with a 7-point scale ranging from 0 (no education) to 6 (theoretically oriented tertiary and post-graduate) on the basis of the International Standard Classification of Education (ISCED) 1997 (OECD, 1999). Parental occupational status was assessed with of the International Standard Classification of Occupations (ISCO-08). Family wealth was assessed with 19 household items (e.g. the number of room space, books, works of art, and electronic devices at home). Finally, the index of ESCS was scaled with the mean of 0 and standard deviation of 1 between the OECD countries. A more precise description of the index of ESCS in the PISA 2015 data is available elsewhere (OECD, 2017a).

3.2.6 Students' risky background characteristics (Studies I and II)

In Studies I and II, **a cumulative risk score** was calculated, referring to the total number of risk factors in students' backgrounds. In Study I, the cumulative risk score included six dichotomized risk factors: immigrant status, risky family structure, previous truancy behavior at school, low family wealth, low maternal education, and male gender. The cumulative risk score included factors that are known to predict weaker school performance. In Study II, the cumulative risk score was composed of five dichotomized risk factors: immigrant status, repetition of a grade, low family wealth, low maternal education, and male gender. The cumulative risk score was calculated as the sum of the dichotomized risk factors (ranging between 0–6 in Study I and between 0–5 in Study II).

Immigration status included three categories: (i) native students (students whose one parent or both parents were born in Finland; (ii) second-generation immigrant students (students who were born in Finland but whose parent(s) were born in some other country); and (iii) first-generation immigrant students (students who were born in some other country and whose parents were born in some other country). In the present study, immigration status was recoded into two categories (0=native students; 1=first- and second-generation immigrant students).

Truancy behavior at school was assessed with three self-rating items: (i) the frequency of coming late for school; (ii) the frequency of skipping whole school day; and (iii) the frequency of skipping classes within school day. The items were rated with a 4-point scale ranging from 1 (none) to 4 (five or more times). When rating the items, students were guided not to count such times of truancy behavior that were not intentional (e.g. resulting from sickness or accident). In the present study, a dichotomous score of truancy behavior was calculated (0=having never come late for school, skipped classes within school day, or skipped whole school day; 1=having at least once come late for school, skipped classes, or skipped whole school day).

Repetition of a grade was recoded into 2 categories (0=did not repeat a grade; 1=repeated a grade).

Family structure was classified into two categories: 0=students coming from two-parent families (students living with a father or step/foster father and a mother or step/foster mother); 1=students coming from single-parent families (students living with mother/female guardian or father/male guardian) and students who did not live with their parents.

Family wealth was recoded into two categories: 0=highest 80% of the sample with regard to family wealth; 1=lowest 20% of the sample with regard to family wealth.

Maternal education was classified into two categories: 0=ISCED level 3 or higher; 1=ISCED level 2 or lower (primary education or lower secondary education).

Gender was classified as follows: 0=female; 1=male.

3.3 STATISTICAL ANALYSES

In all studies of this dissertation, structural equation models were used. Statistical analyses were conducted with STATA SE versions 13.0, 15.0, and 16.0. Students' performance in each cognitive learning outcome was treated as a latent factor with ten plausible values (PISA 2015) or five plausible values (PISA 2012) as indicator (manifest) variables on the basis of the Rasch Model (Nissinen, Rautopuro & Puhakka, 2018). Separate structural equation models were conducted for each cognitive learning outcome (i.e. scientific literacy, mathematical literacy, reading literacy, and collaborative problem-solving). The estimation of the plausible values is described more precisely elsewhere (OECD, 2017a; Nissinen, Rautopuro & Puhakka, 2018). All the predictor variables were treated as observed variables (age, gender, the index of ESCS, teaching strategies, the ICT indices at school, students' background characteristics).

The goodness-of-fit of the structural equation models was assessed with the values of the Root-Mean-Square Error of Approximation (RMSEA), the Comparative Fit Index (CFI), and the Tucker Lewis Index (TLI). It has been showed that the value of RMSEA should be less than 0.06 and the CFI and the TLI should be more than 0.95 (Hu & Bentler, 1999). Additionally, lower values of the $\chi 2$ test of absolute model fit suggest better model fit to the data (Schreiber et al., 2006).

Study I (Student-oriented teaching strategies). In Model 1, students' mathematical learning outcomes were predicted by the frequency of student-oriented teaching strategies in mathematics lessons.

Models 2 investigated whether the association of student-oriented teaching strategies with students' mathematical learning outcomes is modified by students' risky background characteristics (i.e. immigrant status, risky family structure, truancy behavior at school, low family wealth, low maternal education, and male gender). Specifically, in Models 2a–f, the interaction effect of each risk factor with the frequency of student-oriented teaching strategies was added to the model (each risk factor was added to the model separately).

Model 3 investigated whether the association of student-oriented teaching with students' mathematical performance is modified by the cumulative risk score (i.e. the total number of students' risky background characteristics). That is, the interaction of the cumulative risk score with the frequency of student-oriented teaching strategies was added to the model.

Model 4, as additional analysis, investigated the effect of inquiry-based learning practices on students' scientific performance using the PISA 2015 dataset. Hence, the learning outcomes in scientific literacy were predicted by the frequency of inquiry-based learning practices.

All the models were controlled for age, gender, the index of ESCS (i.e. the index of parental economic, social, and cultural status), and the frequency of teacher-directed instruction.

Study II (ICT use at school). Models 5 predicted cognitive learning outcomes (i.e. scientific literacy, mathematical literacy, reading literacy, and collaborative problem-solving) by ICT use at school. Age, gender, and the index of ESCS were included as covariates.

Models 6 investigated whether the association of ICT use at school with cognitive learning outcomes is sustained after controlling for the availability of ICT at school and students' perceived ICT competence. Hence, the availability of ICT at school and students' perceived ICT competence were included as covariates in the model.

Models 7 investigated whether the association of ICT use at school with students' cognitive learning outcomes is modified by students' ICT competence. That is, in models 3, the interaction effect between ICT use at school and students' ICT competence was added to the model.

Models 8 examined whether the association of ICT use at school with cognitive learning outcomes is modified by the availability of ICT at school. Specifically, the interaction effect between ICT use at school and students' ICT competence was added to the model.

Models 9 investigated whether the cumulative risk score of students' background characteristics modifies the association of ICT use at school with cognitive learning outcomes. That is, the interaction effect between the cumulative risk score and ICT use at school was added to the model.

Study III (Participation in early childhood education and care). In Models 10, each cognitive learning outcome (i.e. scientific literacy, mathematical literacy, reading literacy, and collaborative problem-solving) was predicted by the 3-class variable of participation in early childhood education and care (ECEC) (1=preschool at 6 years of age only; 2=preschool at 6 years of age and ECEC started between 3–5 years of age; 3=preschool at 6 years of age and ECEC started before 3 years of age). The models were adjusted for age, gender, and the index of ESCS (i.e. parental socioeconomic status).

Models 11 investigated whether the association of ECEC with cognitive learning outcomes is modified by the index of ESCS (parental socioeconomic status). That is, the index of ESCS and its interaction with the 3-class variable of ECEC was added to the model.

As additional analyses, Models 12 predicted each cognitive learning outcome by the 6-class variable of starting age at ECEC (ranging from 1 to 6 years of age). Child's age at entry into ECEC was treated as a categorical variable because the association of child's age at entry into ECEC with later outcomes was not hypothesized to be linear. The models were adjusted for age, gender, and the index of ESCS.

4 RESULTS

4.1 TEACHING PRACTICES AND LEARNING OUTCOMES

Table 4 shows the results of structural equation models when predicting students' mathematical literacy by the frequency of student-oriented teaching strategies. The results showed that frequent student-oriented teaching strategies were associated with students' weaker performance in mathematical literacy. This finding was adjusted for age, gender, and the index of ESCS (parental socioeconomic status), and the frequency of teacher-directed instruction.

Table 4. The standardized regression coefficients (β) with 95% confidence intervals (CI) of structural equation models, when predicting mathematical literacy by student-oriented teaching.

	Mathematical literacy	
	Model 1	
	β	95% CI
Age	0.060***	0.036; 0.084
Gender[a]	0.067***	0.042; 0.091
The index of ESCS	0.34***	0.32; 0.36
Teacher-directed instruction	0.091***	0.064; 0.12
Student-oriented teaching	-0.25***	-0.28; -0.22

* p<.05 ** p<.01 *** p<.001 N=5660

[a] Female as the reference group.

Next, it was investigated whether students' risky background characteristics modify the association of student-oriented teaching with students' mathematical learning outcomes. The results are presented in Tables 5a and 5b. It was found that the effect of frequent student-oriented teaching on students' mathematical learning outcomes was more adverse (i) among boys than among girls (Table 5a); (ii) among first- or second-generation immigrants than among natives (Table 5a); and (iii) among students with truancy behavior at school than among students with no truancy behavior at school (Table 5a); (iv) among students coming from one-parent families or students who were not living with their parents than among students coming from two-parent families (Table 5b); (v) among students coming from low-wealth families than wealthier families (Table 5b), and (vi) among students with a low-educated than higher-educated mother (Table 5b). All these findings were controlled for age, gender, the index of ESCS (parental socioeconomic status), and the frequency of teacher-directed instruction.

Table 5a. The standardized regression coefficients (β) with 95% confidence intervals (CI) of structural equation models, when predicting mathematical literacy by student-oriented teaching and its interaction with gender, immigrant status, and truancy behavior at school.

	Mathematical literacy					
	Model 2a (*N*=5660)		Model 2b (*N*=5631)		Model 2c (*N*=5589)	
	β	95% CI	β	95% CI	β	95% CI
Age	0.059***	0.036; 0.083	0.050***	0.027; 0.073	0.065***	0.041; 0.088
Gender[a]	0.067***	0.043; 0.091	0.057***	0.034; 0.081	0.072***	0.048; 0.096
The index of ESCS	0.34***	0.32; 0.36	0.26***	0.24; 0.28	0.33***	0.31; 0.35
Teacher-directed instruction	0.092***	0.064; 0.12	0.11***	0.086; 0.14	0.073***	0.046; 0.099
Student-oriented teaching	-0.18***	-0.22; -0.14	-0.19***	-0.22; -0.17	-0.20***	-0.23; -0.16
Gender* Student-oriented teaching	-0.095***	-0.13; -0.059				
Immigration status[b]			0.25***	-0.27; -0.22		
Immigration status* Student-oriented teaching			-0.055***	-0.082; -0.028		
Truancy behavior at school[c]					-0.18***	-0.20; -0.16
Truancy behavior at school* Student-oriented teaching					-0.053**	-0.090; -0.017

* p<.05 ** p<.01 *** p<.001

[a] Female as the reference group.

[b] Native students as the reference group.

[c] Students with no truancy behavior at school as the reference group.

Note: All the interaction analyses (Models 2a–c) were run separately so that each risk factor was added as predictor separately.

Table 5b. The standardized regression coefficients (β) with 95% confidence intervals (CI) of structural equation models, when predicting mathematical literacy by student-oriented teaching and its interaction with risky family structure, low family wealth, and low maternal education.

	Mathematical literacy					
	Model 2d (N=5237)		Model 2e (N=5660)		Model 2f (N=5530)	
	β	95% CI	β	95% CI	β	95% CI
Age	0.062***	0.037; 0.087	0.059***	0.036; 0.083	0.056***	0.032; 0.081
Gender[a]	0.070***	0.045; 0.095	0.069***	0.044; 0.093	0.068***	0.044; 0.093
The index of ESCS	0.32***	0.30; 0.35	0..36***	0.34; 0.38	0.31***	0.28; 0.33
Teacher-directed instruction	0.089***	0.060; 0.12	0.088***	0.061; 0.12	0.092***	0.065; 0.12
Student-oriented teaching	-0.23***	-0.26; -0.19	-0.22***	-0.25; -0.19	-0.23***	-0.26; -0.21
Risky family structure[b]	-0.053***	-0.078; -0.028				
Risky family structure* Student-oriented teaching	-0.032*	-0.060; -0.0038				
Low family wealth[c]			0.063***	0.038; 0.089		
Low family wealth* Student-oriented teaching			-0.056***	-0.084; -0.029		
Low maternal education[d]					-0.045**	-0.083; -0.017
Low maternal education* Student-oriented teaching					-0.029*	-0.055; -0.0030

* $p<.05$ ** $p<.01$ *** $p<.001$

[a] Female as the reference group.

[b] Students coming from two-parent families as the reference group.

[c] Student coming from high- or average-wealthy families as the reference group.

Note: All the interaction analyses (Models 2d–f) were run separately so that each risk factor was added to the predictors separately.

Thereafter, it was investigated whether the cumulative risk score modifies the association of student-oriented teaching with students' mathematical learning outcomes. The results are presented in Table 6. A negative interaction effect was obtained between student-oriented teaching and the cumulative risk score when predicting students' mathematical performance. This indicated that the effect of student-oriented teaching on students' mathematical learning outcomes was more negative at higher than lower levels of students' risky background characteristics (see Figure 7). This finding was controlled for age, gender, the index of ESCS (parental socio-economic factors), and the frequency of teacher-directed instruction.

Table 6. The standardized regression coefficients (β) with 95% confidence intervals (CI) of structural equation models, when predicting mathematical literacy by student-oriented teaching and its interaction with the cumulative risk score.

	Mathematical literacy	
	Model 3	
	β	95% CI
Age	0.057***	0.032; 0.082
Gender[a]	0.16***	0.13; 0.18
The index of ESCS	0.25***	0.22; 0.27
Teacher-directed instruction	0.092***	0.063; 0.12
Student-oriented teaching	-0.053*	-0.10; -0.0038
Cumulative risk score	-0.20***	-0.23; -0.17
Cumulative risk score* Student-oriented teaching	-0.20***	-0.25; -0.15

* p<.05 ** p<.01 *** p<.001 N=5052

[a] Female as the reference group.

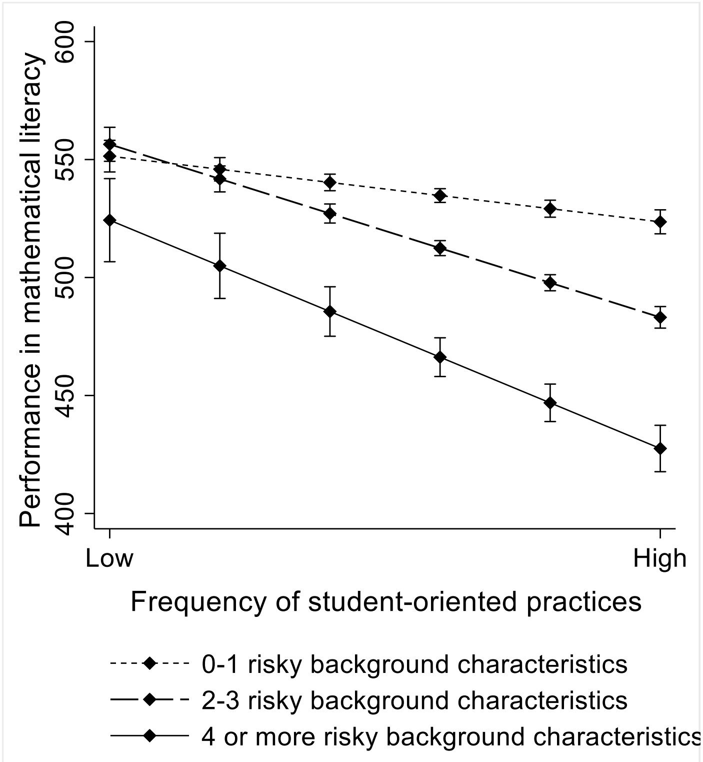


Figure 7. Predicted marginal means with 95% confidence intervals of students' mathematical performance at different frequencies of student-oriented teaching practices (ranging from 10th percentile to 90th percentile) and at different numbers of risky background characteristics (at most 1 risk factor (N=2511); 2–3 risk factors (N=2187); 4 or more risk factors (N=354). Adjusted for age, gender, the index of ESCS, and the frequency of teacher-directed practices.

Finally, as additional analysis, the Finnish PISA 2015 data (N=5430) was used. It was investigated whether inquiry-based learning practices in science lessons are related to students' learning outcomes in scientific literacy. Table 7 presents the results. It was found that frequent inquiry-based science teaching and learning practices were associated with students' weaker performance in scientific literacy (B=-0.08, p<.001). Moreover, frequent teacher-directed science instruction was related to students' better performance in scientific literacy (B=0.19, p<.001). Age, gender, and the index of ESCS were controlled for.

Overall, when predicting cognitive learning outcomes by teaching strategies, the CFI, TLI and RMSEA indices of all the structural equation models were excellent (CFI=1.000; TLI=1.000; RMSEA≤.009) (see Table 8).

Table 7. The standardized regression coefficients (β) with 95% confidence intervals (CI) of structural equation models, when predicting scientific literacy by inquiry-based teaching in the PISA 2015 data.

	Scientific literacy (Model 4)	
	β	95% CI
Age	0.060***	0.031; 0.080
Gender[a]	-0.068***	-0.093; -0.043
The index of ESCS	0.31***	0.29; 0.33
Teacher-directed instruction	0.19***	0.16; 0.21
Inquiry-based teaching	-0.075***	-0.10; -0.050

* p<.05 ** p<.01 *** p<.001 N=5430
[a] Female as the reference group.

Table 8. The goodness-of-fit statistics of the structural equation models when predicting cognitive learning outcomes by teaching strategies and risky background factors.

	Goodness-of-fit statistics					
	χ^2 value	*df*	*p*	TLI	CFI	RMSEA
Model 1	15.377	25	0.932	1.000	1.000	0.000
Model 2a	19.451	29	0.909	1.000	1.000	0.000
Model 2b	19.013	33	0.975	1.000	1.000	0.000
Model 2c	22.843	33	0.907	1.000	1.000	0.000
Model 2d	28.012	33	0.714	1.000	1.000	0.000
Model 2e	27.326	33	0.745	1.000	1.000	0.000
Model 2f	23.787	33	0.880	1.000	1.000	0.000
Model 3	23.970	33	0.875	1.000	1.000	0.000
Model 4	115.88	80	0.005	1.000	1.000	0.009

RMSEA = the Root Mean Square Error of Approximation.
CFI = the Comparative Fit Index.
TLI = the Tucker Lewis Index.

4.2 DIGITAL LEARNING MATERIALS AT SCHOOL AND LEARNING OUTCOMES

Table 9 shows the results, when predicting students' cognitive learning outcomes by ICT use at school. It was found that frequent ICT use at school was associated with weaker cognitive learning outcomes in all the domains under investigation: lower scores of scientific literacy, mathematical literacy, reading literacy, and collaborative problem-solving (Models 5). All these associations were controlled for age, gender, and the index of ESCS (i.e. parental socioeconomic status). When adjusted also for the availability of ICT at school and students' perceived ICT competence (Models 6), all the significant associations of ICT use at school with lower cognitive learning outcomes remained.

Table 9. The standardized coefficients (Β) with 95% confidence intervals of the ICT indices when predicting students' cognitive learning outcomes using structural equation models.

	Models 5		Models 6	
	β	95% CI	β	95% CI
Scientific literacy				
ICT use at school	-0.14***	-0.16; -0.11	-0.16***	-0.19; -0.13
ICT availability at school			-0.0095	-0.036; 0.017
Students' ICT competence			0.11***	0.085; 0.14
Mathematical literacy				
ICT use at school	-0.11***	-0.14; -0.083	-0.13***	-0.16; -0.10
ICT availability at school			-0.016	-0.042; 0.011
Students' ICT competence			0.12***	0.093; 0.15
Reading literacy				
ICT use at school	-0.13***	-0.16; -0.11	-0.15***	-0.18; -0.13
ICT availability at school			-0.016	-0.042; 0.0092
Students' ICT competence			0.13***	0.094; 0.15
Collaborative problem-sol-				
ICT use at school	-0.13***	-0.16; -0.11	-0.15***	-0.18; -0.12
ICT availability at school			-0.0036	-0.030; 0.023
Students' ICT competence			0.083***	0.056; 0.11

* p<.05 *** p<.001 ICT = Information and communications technology.
Models 5: Adjusted with baseline covariates (age, gender, the index of ESCS). Note: The estimates of the baseline covariates were excluded from the table.
Models 6: Adjusted also with ICT availability at school and students' ICT competence.

Next, it was investigated whether the associations of ICT use at school with cognitive learning outcomes is moderated by ICT availability at school or students' perceived ICT competence. The results are presented in Table 10. When predicting cognitive learning outcomes (scientific literacy, mathematical literacy, reading literacy, and collaborative problem-solving), use of ICT at school had a significant negative interaction effect with (i) student's perceived ICT competence (Models 7) and (ii) ICT availability at school (Models 8). The negative main effect of ICT use at school on students' cognitive learning outcomes remained significant after adding its interaction with students' ICT competence to the model. Instead, after adding the interaction between ICT use and ICT availability at school, the main effect of ICT use at school on students' cognitive learning outcomes disappeared.

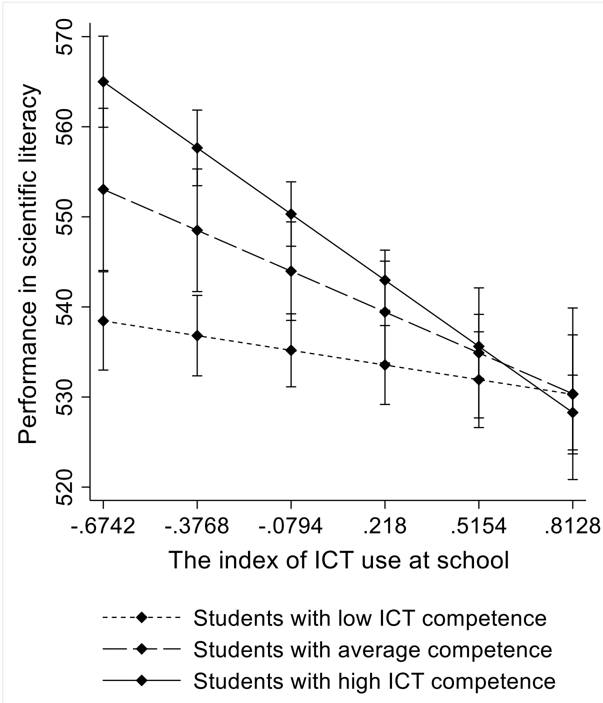
Taken together, the findings indicated that frequent ICT use had a negative effect on students' cognitive learning outcomes at all levels of students' ICT competence, but the effect was more negative at high vs. low levels of students' ICT competence. Further, frequent ICT use at school had a negative effect on students' cognitive learning outcomes at high levels but not at low levels of ICT availability at school (see Figure 8).

Table 10. The standardized coefficients (*β*) with 95% confidence intervals of the ICT indices and their interactions when predicting students' learning outcomes with structural equation models.

	Models 7		Models 8	
	β	95% CI	β	95% CI
Scientific literacy				
ICT use at school	-0.15***	-0.18; -0.12	-0.057	-0.13; 0.014
ICT availability at school	-0.012	-0.038; 0.015	-0.0060	-0.033; 0.021
Students' ICT competence	0.12***	0.094; 0.15	0.11***	0.084; 0.14
ICT use at school* Students' ICT competence	-0.073***	-0.099; -0.046		
ICT use at school* ICT availability at school			-0.11**	-0.18; -0.038
Mathematical literacy				
ICT use at school	-0.12***	-0.15; -0.093	-0.045	-0.12; 0.027
ICT availability at school	-0.018	-0.044; 0.0082	-0.013	-0.039; 0.014
Students' ICT competence	0.13***	0.10; 0.16	0.12***	0.092; 0.15
ICT use at school* Students' ICT competence	-0.074***	-0.10; -0.048		
ICT use at school* ICT availability at school			-0.091*	-0.16; 0.019
Reading literacy				
ICT use at school	-0.14***	-0.17; -0.12	-0.011	-0.081; 0.058
ICT availability at school	-0.019	-0.044; 0.0067	-0.012	-0.037; 0.014
Students' ICT competence	0.13***	0.10; 0.16	0.12***	0.093; 0.14
ICT use at school* Students' ICT competence	-0.079***	-0.10; -0.054		
ICT use at school* ICT availability at school			-0.15***	0.22; -0.082
Collaborative problem-solving				
ICT use at school	-0.14***	-0.17; -0.11	-0.012	-0.082; 0.060
ICT availability at school	-0.0056	-0.032; 0.021	0.0011	-0.025; 0.028
Students' ICT competence	0.090***	0.063; 0.12	0.081***	0.054; 0.11
ICT use at school* Students' ICT competence	-0.064***	-0.091; -0.038		
ICT use at school* ICT availability at school			-0.15***	-0.22; -0.077

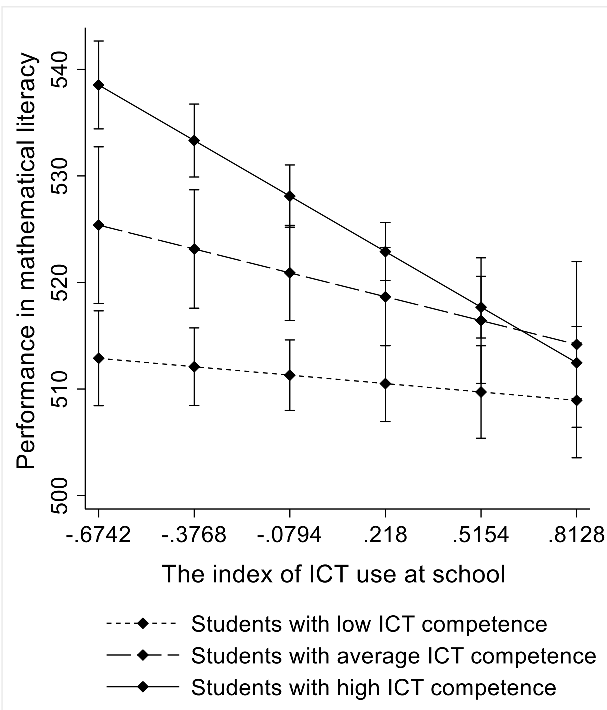
* p<.01 *** p<.001 ICT = Information and communications technology.
Note: All the models were adjusted for age, sex, and the index of ESCS. The estimates of these co-variates were excluded from the Table.
Models 7: The interaction between ICT use at school and students' ICT competence was added to the model.
Models 8: The interaction between ICT use at school and ICT availability at school was added to the model.

(a)



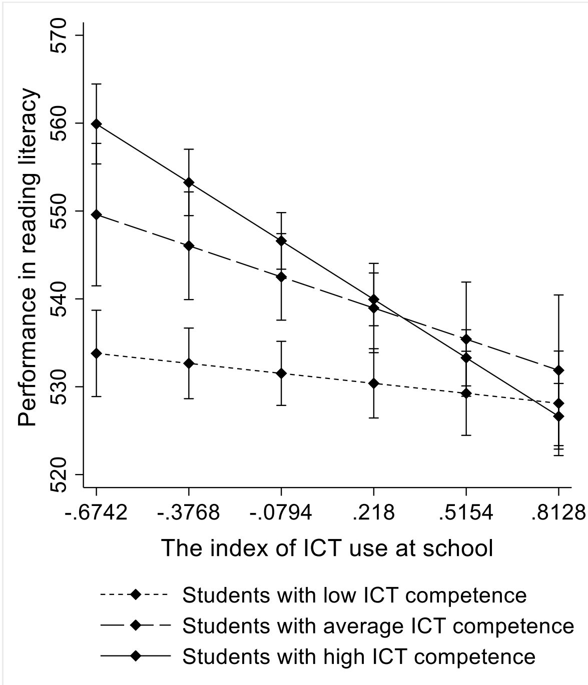
Performance in scientific literacy
520
530
540
550
560
570
-.6742
-.3768
-.0794
.218
.5154
.8128
The index of ICT use at school
Students with low ICT competence
Students with average competence
Students with high ICT competence

(b)



Performance in mathematical literacy
500
510
520
530
540
-.6742
-.3768
-.0794
.218
.5154
.8128
The index of ICT use at school
Students with low ICT competence
Students with average ICT competence
Students with high ICT competence

(c)


Performance in reading literacy
520
530
540
550
560
570
-.6742
-.3768
-.0794
.218
.5154
.8128
The index of ICT use at school
Students with low ICT competence
Students with average ICT competence
Students with high ICT competence

(d)

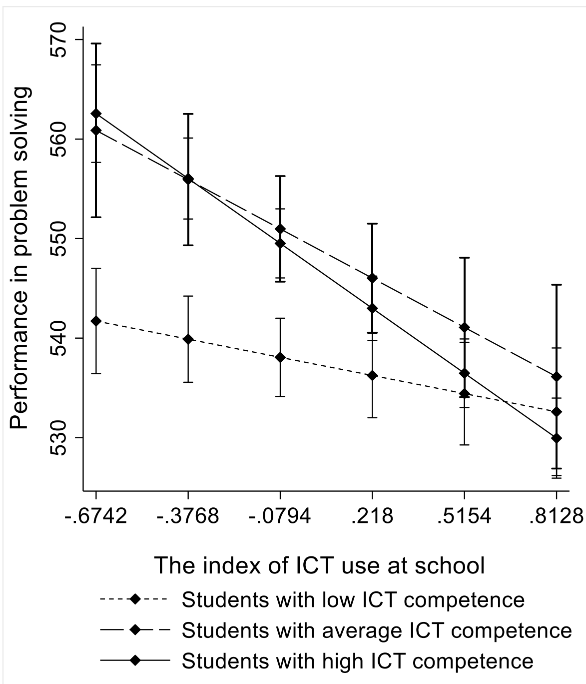

Performance in problem solving
530
540
550
560
570
-.6742
-.3768
-.0794
.218
.5154
.8128
The index of ICT use at school
Students with low ICT competence
Students with average ICT competence
Students with high ICT competence

Figure 8. Predicted marginal means with 95% confidence intervals of students' learning outcomes in (a) scientific literacy, (b) mathematical literacy, (c) reading literacy, and (d) collaborative problem solving at different levels of ICT use at school (ranging from 10th percentile to 90th percentile) and among students with low (lowest 30%), average, and high (highest 30%) ICT competence. Adjusted for age, gender, the index of ESCS, and availability of ICT at school.

Finally, it was investigated whether the cumulative risk score of students' risky background characteristics moderates the association of ICT use at school with students' cognitive learning outcomes. The results are shown in Table 11. It was obtained a significant negative interaction effect between the cumulative risk score and ICT use at school when predicting students' cognitive learning outcomes (i.e. scientific literacy, mathematical literacy, reading literacy, and collaborative problem-solving). This indicated that frequent ICT use at school had a more negative effect on learning outcomes in students with high vs. low levels of risky background characteristics.

The CFI, TLI and RMSEA indices of the structural equation models were excellent (CFI≥.998; TLI≥.998; RMSEA≤.017) (see Table 12).

Table 11. The standardized coefficients (β) with 95% confidence intervals of the ICT use, cumulative risk score, and their interaction when predicting students' cognitive learning outcomes with structural equation models.

	Model 9	
	β	95% CI
Scientific literacy		
ICT use at school	-0.117***	-0.163; -0.072
Cumulative risk score	-0.106***	-0.143; -0.069
ICT use at school* Cumulative risk score	-0.056*	-0.101; -0.016
Mathematical literacy	-0.096***	-0.141; -0.051
ICT use at school	-0.136***	-0.173; -0.100
Cumulative risk score	-0.048*	-0.092; -0.003
ICT use at school* Cumulative risk score		
Reading literacy		
ICT use at school	-0.108***	-0.152; -0.064
Cumulative risk score	-0.102***	-0.138; -0.066
ICT use at school* Cumulative risk score	-0.063**	-0.107; -0.020
Collaborative problem-solving		
ICT use at school	-0.117***	-0.163; -0.072
Cumulative risk score	-0.124***	-0.160; -0.087
ICT use at school* Cumulative risk score	-0.045*	-0.090; -0.001

* p<.01 *** p<.001 N=4925
ICT = Information and communications technology.
Note: All the models were adjusted for age, sex, the index of ESCS, students' ICT competence, and ICT availability at school. The estimates of these covariates were excluded from the table.

Table 12. The goodness-of-fit statistics of all the structural equation models when investigating the association of ICT use at school with cognitive learning outcomes.

	χ^2 value	*df*	*p*	RMSEA	CFI	TLI
Scientific literacy						
Model 5	71.400	71	0.464	0.001	1.000	1.000
Model 6	94.377	89	0.328	0.003	1.000	1.000
Model 7	104.835	98	0.300	0.004	1.000	1.000
Model 8	111.320	98	0.169	0.005	1.000	1.000
Mathematical literacy						
Model 5	132.935	71	<0.001	0.013	0.999	0.999
Model 6	170.788	89	<0.001	0.014	0.999	0.999
Model 7	182.219	98	<0.001	0.013	0.999	0.999
Model 8	177.780	98	<0.001	0.013	0.999	0.999
Reading literacy						
Model 5	162.957	71	<0.001	0.016	0.999	0.999
Model 6	218.350	89	<0.001	0.017	0.998	0.998
Model 7	224.626	98	<0.001	0.016	0.998	0.998
Model 8	247.120	98	<0.001	0.017	0.998	0.998
Collaborative problem-						
Model 5	158.34	71	<0.001	0.016	0.998	0.998
Model 6	186.37	89	<0.001	0.015	0.998	0.998
Model 7	198.561	98	<0.001	0.014	0.998	0.998
Model 8	207.430	98	<0.001	0.015	0.998	0.998

RMSEA = the Root Mean Square Error of Approximation. CFI = the Compar-
TLI = the Tucker Lewis Index. *N*=5037

4.3 PARTICIPATION IN EARLY EDUCATION AND CARE AND LEARNING OUTCOMES

Table 13 presents the results of structural equation models, when predicting students' cognitive learning outcomes by participation in early childhood education and care (ECEC) using the three-class variable of ECEC. It was found that students who had participated in ECEC before 3 years of age performed slightly better in mathematical literacy (B=7.96, p=.016) when compared to participants who had only participated in preschool at 6 years of age. After Bonferroni-correction, however, this association was non-significant. In any other cognitive learning outcome (i.e. scientific literacy, reading literacy, or collaborative problem-solving), students who had only participated in preschool at 6 years of age did not differ from (1) students who had participated in preschool at 6 years of age and started in ECEC at 3–5 years of age or (2) students who had participated in preschool at 6 years of age and started in ECEC before 3 years of age. All these associations were controlled for age, gender, and the index of ESCS (parental socioeconomic status).

Table 13. The regression coefficients (B) with 95% confidence intervals (CI) of structural equation models, when predicting cognitive learning outcomes by participation in early childhood education and care (categorical variable).

	Scientific literacy		Mathematical literacy		Reading literacy		Collaborative problem-solving	
	B	95% CI	B	95% CI	B	95% CI	B	95% CI
Age	14.58**	6.01; 23.14	11.07**	4.17; 17.98	15.62***	8.08; 23.16	16.79***	8.47; 25.10
Gender[1]	-	-20.33; -10.58	-3.05	-6.98; 0.88	-41.42***	-45.73; -37.10	-45.71***	-50.49; -40.93
Index of ESCS	38.56***	35.20; 41.92	35.12***	32.39; 37.86	34.63***	31.66; 37.60	29.87***	26.60; 33.15
Participation in ECEC								
Preschool at 6 years of age[2]	-	-	-	-	-	-	-	-
Preschool at 6 years of age and ECEC started in 3–5 years of age	-3.91	-10.41; 2.59	0.86	-4.38; 6.10	-3.54	-9.26; 2.19	-2.60	-8.90; 3.71
Preschool at 6 years of age and ECEC started before 3 years of	3.81	-4.21; 11.84	7.96*	1.49; 14.43	4.45	-2.62; 11.51	2.36	-5.43; 10.15

*** p<.001 **p<.01 *p<.05 [1] Girls as the reference group. [2] The reference group. N=4634.

Next, it was investigated whether the index of ESCS (parental socioeconomic status) modifies the association of participation in ECEC with cognitive learning outcomes. The results are presented in Table 14. It was obtained a significant positive interaction effect between the index of ESCS and participation in ECEC when predicting scientific literacy (B=11.29, p=.047). This interaction, however, was non-significant after Bonferroni-correction. When predicting other cognitive learning outcomes (reading literacy, mathematical literacy, or collaborative problem-solving), there were not any significant interactions between the index of ESCS and participation in ECEC.

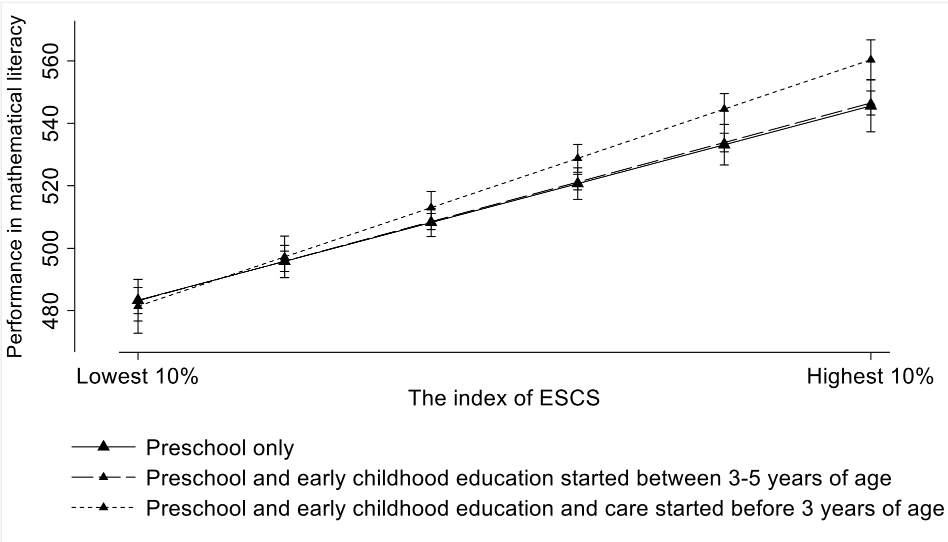
Taken together, at a trend level, the findings suggested that participation in ECEC before preschool (before 6 years of age) appeared to have a slightly more positive effect on cognitive learning outcomes at 15 years of age among students with higher than lower index of ESCS (parental socioeconomic status). The findings are illustrated in Figures 9a–d.

Table 14. The regression coefficients (B) with 95% confidence intervals (CI) of structural equation models when predicting cognitive learning outcomes by participation in early childhood education and care (ECEC) and the index of ESCS.

	Scientific literacy		Mathematical literacy		Reading literacy		Collaborative problem-solving	
	B	95% CI	B	95% CI	B	95% CI	B	95% CI
Age	14.73**	6.17; 23.30	11.15**	4.24; 18.05	15.72***	8.17; 23.26	16.80***	8.48; 25.11
Gender[1]	-15.45***	-20.32; -10.57	-3.01*	-6.94; 0.92	-41.43***	-45.75; -37.11	-45.68***	-50.46; -40.90
ECEC								
Preschool at 6 years of age[2]	-	-	-	-	-	-	-	-
Preschool at 6 years of age and ECEC started in 3–5 years of age	-4.05	-10.65; 2.55	1.13	-4.19; 6.45	-3.75	-9.56; 2.06	-2.34	-8.74; 4.07
Preschool at 6 years of age and ECEC started before 3 years of age	0.32	-8.43; 9.06	4.60	-2.45; 11.65	3.07	-4.63; 10.77	0.85	-7.64; 9.34
Index of ESCS	34.10***	26.28; 41.92	33.18***	26.87; 39.50	31.94***	25.05; 38.84	29.78***	22.18; 37.38
Index of ESCS*ECEC								
Index of ESCS* Preschool at 6 years of age[2]	-	-	-	-	-	-	-	-
Index of ESCS* Preschool at 6 years of age and ECEC started in 3–5 years of age	3.85	-5.01; 12.71	0.57	-6.57; 7.72	2.75	-5.05; 10.55	-0.78	-9.38; 7.82
Index of ESCS* Preschool at 6 years of age and ECEC started before 3 years of age	11.29*	0.15; 22.44	8.89	-0.093; 17.88	5.22	-4.59; 15.03	3.35	-7.47; 14.16

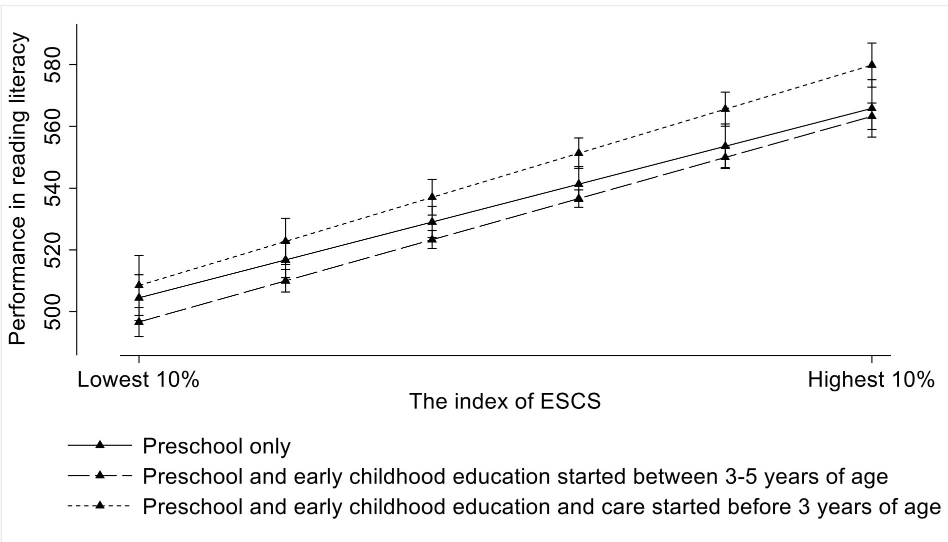
*** $p<.001$ ** $p<.01$ * $p<.05$ N=4634. [1] Females as the reference group. [2] The reference group.
ECEC=Early childhood education and care. ESCS=The index of economic, social, and cultural status.

(a)



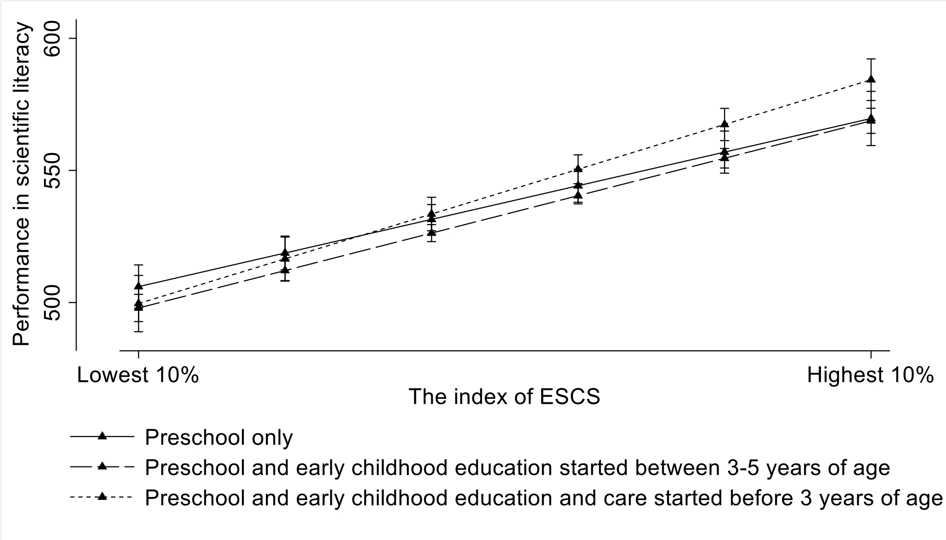
Performance in mathematical literacy
480
500
520
540
560
Lowest 10%
Highest 10%
The index of ESCS
Preschool only
Preschool and early childhood education started between 3-5 years of age
Preschool and early childhood education and care started before 3 years of age

(b)



Performance in reading literacy
500
520
540
560
580
Lowest 10%
Highest 10%
The index of ESCS
Preschool only
Preschool and early childhood education started between 3-5 years of age
Preschool and early childhood education and care started before 3 years of age

(c)



(d)

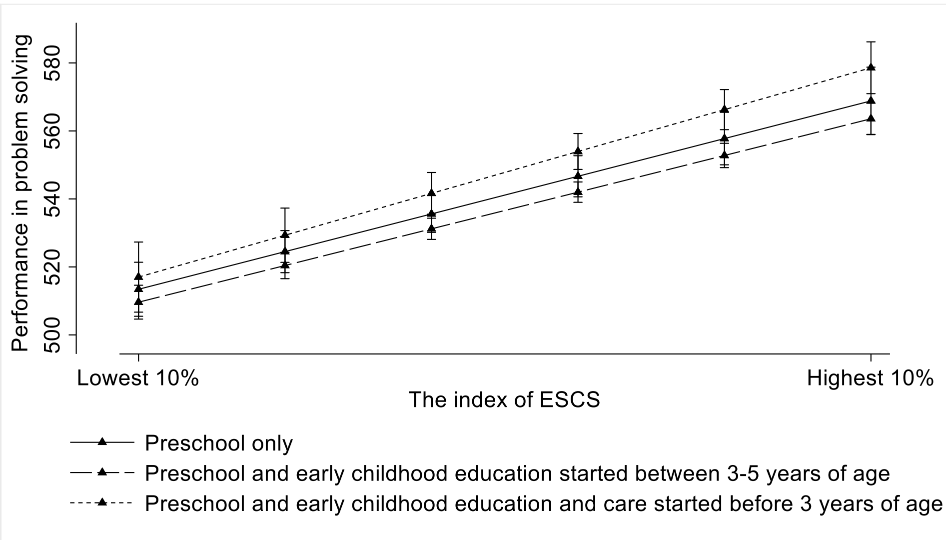


Figure 9. Predicted means with 95% confidence intervals of students' learning outcomes in (a) mathematical literacy, (b) reading literacy, (c) scientific literacy, and (d) collaborative problem-solving separately for students with different exposure to early childhood education and care and with different levels of the index of ESCS (parental socioeconomic status). Note: the mean of the plausible values 1–10 of cognitive learning outcomes was used in this Figure.

Finally, it was investigated whether the 6-class variable of child's starting age at ECEC is linked with cognitive learning outcomes at 15 years of age. The results are shown in Table 15. It was found that students who had started in ECEC at 2 years of age performed slightly better in mathematical literacy at 15 years of age, when compared to students who had only participated in preschool at 6 years of age (B=8.48, p=.015). Additionally, students who had started in ECEC at 5 years of age had slightly weaker performance in reading literacy, when compared to students who had only participated in preschool (B=-8.62, p=.014). After Bonferroni-correction, these associations were non-significant. Taken together, after Bonferroni-correction, students who had only participated in preschool at 6 years of age did not differ in any cognitive learning outcome at 16 years of age from students who had started in ECEC at any other age between 1–5 years.

Table 15. The regression coefficients (B) with 95% confidence intervals (CI) of structural equation models, when predicting cognitive learning outcomes by the age of entry into early education and care.

	Cognitive learning outcomes							
	Scientific literacy		Mathematical literacy		Reading literacy		Collaborative problem-sol-	
	B	95% CI	B	95% CI	B	95% CI	B	95% CI
Age	14.72**	6.14; 23.30	10.91**	4.11; 17.72	15.16***	7.61; 22.71	16.61***	6.21; 23.26
Gender	-15.24***	-20.12; -10.35	-2.98	-6.85; 0.89	-41.27***	-45.59; -36.95	-45.69***	-19.98; -10.27
The index of ESCS	38.48***	35.10; 41.85	34.26***	31.56; 36.96	34.21***	31.22; 37.19	29.72***	34.89; 41.60
Age at entry into ECEC								
6 years of age[1]	-	-	-	-	-	-	-	-
5 years of age	-3.66	-11.44; 4.12	0.89	-5.28; 7.07	-8.62*	-15.46; 1.77	-4.70	-12.24; 2.86
4 years of age	-7.50	-15.45; 0.44	-2.12	-8.42; 4.19	-3.60	-10.60; 3.39	-2.64	-10.36; 5.07
3 years of age	-0.93	-8.67; 6.82	2.57	-3.58; 8.71	1.54	-5.27; 8.35	-0.49	-8.00; 7.02
2 years of age	4.98	-3.79; 13.75	8.48*	1.52; 15.43	5.82	-1.89; 13.54	3.98	-4.53; 12.49
1 year of age	1.31	-10.36; 12.97	5.94	-3.31; 15.20	1.71	-8.55; 11.97	-1.28	-12.61; 10.04

* $p<.05$ ** $p<.01$ *** $p<.001$ [1] The reference group. N=4634

5 DISCUSSION

5.1 THE ASSOCIATION OF SELF-DIRECTED LEARNING PRACTICES AND DIGITAL LEARNING MATERIALS WITH LEARNING OUTCOMES

5.1.1 Main findings

Learning outcomes. The results of Studies I and II indicated that frequent use of self-directed learning practices or digital learning materials was related to weaker learning outcomes in several knowledge domains at 15 years of age. Instead, frequenct teacher-directed practices were related to higher learning outcomes. These findings were sustained after controlling for age, gender, and parental socioeconomic status (the index of economic, social, and cultural status).

The findings are in line with a number of studies that also have not obtained any positive impact of self-directed practices on students' learning outcomes in children or adolescents (e.g. Gao et al., 2014; Klahr & Nigam, 2004; Maxwell et al., 2015; Mergendoller et al., 2000; Schaal & Bogner, 2005; Sturm & Bogner, 2008; Wolf & Fraser, 2008). Moreover, there have been numerous studies obtaining a negative association between digital learning materials and learning outcomes (e.g. Carter et al., 2017; Chiu et al., 2013; Douglas et al., 2012; Fried et al., 2008; Hembrooke et al., 2003; Jacobsen et al., 2011; McKenzie, 2013; Mueller et al., 2014; Sana et al., 2013; Wood et al., 2012; Yulianto et al., 2016).

Equality in learning outcomes. The findings of Studies I and II showed that frequent use of self-directed teaching practices or digital learning materials had more negative impact on students' learning outcomes in students with (vs. without) risky background. In Studies I and II, the focus was on the following risk factors: male gender, among first- or second-generation immigrant status, single-parent family, low family wealth, low maternal education, truancy behavior at school, and repetition of a grade. Taken together, the findings suggest that frequent use of self-directed learning practices or digital learning material may increase variance in learning outcomes between students coming from different backgrounds in Finland.

The findings related to inequality were in accordance with previous research literature. Specifically, it has been suggested that frequent use of self-directed practices may increase inequality between students (Connor, Morrison, & Katch, 2004; Kirschner et al., 2006; Maxwell et al., 2005; Von Secker & Lissitz, 1999; Wolf & Fraser, 2008; Zohar & Dori, 2003). Further, it has been postulated that frequent use of digital learning materials may expand gaps between different student groups (Ayres, 2005; Jacobsen & Forste, 2011; Kalyuga et al., 2003; Lee, 2005; Levinson et al., 2007; Paas et al., 2004; Van Merriënboer & Garg et al., 1999; Volman & van Eck, 2001).

5.1.2 Required level of self-directedness

Student-oriented and inquiry-based learning practices. An efficient use of self-directed practices requires a variety of skills from the student, including autonomy, self-directedness, self-inhibition, concentration skills, initiative, and flexibility. When using self-directed practices, the student needs to set his/her learning goals, to select a suitable physical space for learning, to make a plan of the working strategies and schedule, and to plan an appropriate order of learning tasks. Adolescents with low self-directedness, however, may have challenges to regulate their behavior in line with learning goals, to control behavioral impulses, or to self-monitor their proceeding toward the learning goals (Cohen & Lieberman, 2010; Miyake et al., 2000; Packwood et al., 2011; Strayhorn, 2002a). Further, low self-directedness refers to a stronger tendency to give up at moments of frustration and to seek for such tasks that arouse immediate reward and enjoyment (Cohen & Lieberman, 2010; Miyake et al., 2000; Packwood et al., 2011; Strayhorn, 2002a).

In our study, it was found that, among 15-year-old students, frequent use of self-directed practices is related to lower learning outcomes. This is highly in accordance with previous research. Specifically, it has been shown that the development of self-directedness is a slow process over age and is not completed before early adulthood (Harden & Tucker-Drob, 2011; Johnson et al., 2016; Gogtay et al., 2004; Luna et al., 2001; Romer et al., 2017). Research evidence has shown that self-directedness develops particularly slowly over age in children with developmental risk factors: for example, in children with neuropsychiatric symptoms, low family SES, or low school performance (e.g. Berger et al., 2013; Brown et al., 2009; Mann et al., 2015; Raver et al., 2013; Rhoades et al., 2011; Sarsour et al., 2011; Smith-Spark et al., 2009). Importantly, the development of self-directedness is very strongly based on genetic factors so that the role of environmental factors is small (Anokhin et al., 2017; Beaver et al., 2013; Coyne & Wright, 2014).

Digital learning materials. In many cases, digital learning materials are used to promote students' greater flexibility, freedom, and autonomy and to reduce the use of teacher-centered learning methods (Downes et al., 2002; Fleischer, 2012). Hence, it has been stated that digital learning materials enable a more self-directed and self-regulated style of learning (Hromalik & Koszalka, 2018; Sung et al., 2016). Hence, use of digital technologies requires abilities to set one's learning goals, abilities to select appropriate digital applications or device, abilities to select a suitable environment where to use digital technologies (e.g. when using a tablet), and abilities to maintain one's attention in the content of the digital learning material (not merely in the technical use of the device).

In several previous studies, the samples have consisted of volunteers that are likely to be more digitally-capable individuals than on average (e.g. Bruce-Low et al., 2013), students with appropriate device, or students with more privileged backgrounds than on average (e.g. Basoklu & Akdemir, 2010; Bruce-Low et al., 2013; Gulek et al., 2005). Our findings indicate that, when implemented to the whole age group of students at comprehensive school, use of digital learning materials increases variance between students with different cognitive abilities, digital competencies, and family backgrounds. Consequently, it has been noted that students with low cognitive abilities or low content knowledge may not possess all the necessary skills in order to use digital learning materials in a goal-oriented and efficient way (Kalyuga et al., 2003; Paas et al., 2004; Van Merriënboer & Ayres, 2005; Garg et al., 1999; Levinson et al., 2007). Moreover, teacher may not have resources to provide sufficient guidance and screening in the use of digital learning technologies in practical school environments.

5.1.3 Working memory load

Self-directed learning practices. The effect of self-directed learning practices with weaker learning outcomes may be partially accounted by excessive cognitive overload. This is because, firstly, self-directed practices commonly includes students' independent problem-solving and self-directed investigations (Schunk, 2008; Terhart, 2003). In this way, students acquire only some pieces of information at a time and, in many cases, the new pieces of information may not be coherently built on students' previous knowledge (Kirschner et al., 2006). Secondly, self-directed practices may direct students' attention to such behaviors that are unrelated to the primary content of the learning material (Kirschner et al., 2006): for example, group interactions. Overall, self-directed learning practices have been criticized for that they may direct students' attention away from the learning content and, hence, eventually result in a lack of content knowledge (Furtak & Kunter, 2012; Schaal & Bogner, 2005; Scheyvens et al., 2008).

Digital learning material. Also, the observed association between frequent digital learning material and weaker learning outcomes may be partially explained by working memory overload. It has been demonstrated that the use of digital learning materials may result in frequent task-switching and disruptions in one's concentration on the learning material (Kirschner & Bruyckere, 2017; Loh & Kanai, 2016; Ophir, Nass, & Wagner, 2009; Wood et al., 2012). This is because, in many cases, the use of digital learning materials includes a variety of serial cognitive tasks, such as processing the content of the learning material, the technical use of the device, and cognitive inhibition of using the device for personal purposes (e.g. social media). In this way, different tasks may compete with each other for the limited resources of the working memory and result in working memory overload (Kirschner & Bruyckere, 2017; Wood et al., 2012). In line with this, it has been obtained in Finland that excessive Internet use may predict burnout that, in turn, predicts depressive symptoms (Salmela-Aro et al., 2017).

Working memory load in students of risk groups. Children coming from low-SES families (e.g. low parental education or low family income) are found to have a lower capacity of working memory than children coming from high-SES families (Finn et al., 2017; Hackman et al., 2014). Further, students with dyslexia, ADHD symptoms, or depressive symptoms have on average weaker functioning of working memory (Kofler et al., 2011; Rose & Ebmeier, 2006; Smith-Spark & Fisk, 2007). Consequently, students belonging to risk groups are more susceptible to working memory overload.

5.1.4 Students' digital competencies and availability of digital device

Students' competence in using digital learning materials. Previously, it has been suggested that students' low competencies in using technical devices for learning purposes might explain some negative findings related to the use of digital learning materials at school (Carter, Greenberg & Walker, 2017). In Study II, however, it was found that frequent use of digital learning materials had a more negative effect on learning outcomes at high (vs. low) levels of students' competence in using digital learning materials. Thus, the findings indicate that the negative effect of digital learning materials on learning outcomes may not be accounted by low levels of students' digital competence.

It may be that students with high ICT competence (i.e. better knowledge about the use of applications, games, and websites) are more prone to use the device for other than learning purposes. This may result in more frequent task-switching and eventually predispose to working memory overload. This is in line with previous studies obtaining that there are several dimensions of using digital technologies, namely social networking oriented participation, knowledge-oriented participation, media-oriented participation, action gaming, and social gaming (Hietajärvi et al., 2019). Further, the results showed that higher social-oriented use of digital technologies was related to lower study engagement and higher burnout; play-oriented use was related to higher cynicism; and knowledge-oriented use was related to higher study engagement (Hietajärvi et al., 2019). Similar findings have been obtained also in other studies. For example, gaming or coding-related use of digital technologies is related to better working memory functioning, while multitasking-including use of digital technologies is related to lower task performance (Moisala et al., 2016, 2017). Further, excessive Facebook use is related to higher experiences of regret, possibly via conflicts with friends (Dhir et al., 2016). Moreover, there is evidence that hanging-related ICT-engagement outside of school is related to students' higher indifference toward school work (Hietajärvi et al., 2015). Nevertheless, in one study, students reported to use digital technologies for knowledge acquisition and mechanical tasks but, however, ICT use was related to lower school value and burnout symptoms (Halonen et al., 2017). Taken together, it may be that many adverse effects of using digital technologies may be explained by multi-tasking or by use of the device for other than learning purposes. Hence, in line with previous studies (e.g. Vainikainen et al., 2015), learning skills how to learn appears to be crucial in comprehensive school.

Availability of digital device at school. Previously, it has been postulated that a limited number of digital devices may interfere with concentration on the learning material (e.g. Balanskat et al., 2006). This is because a limited number of devices may result in a shared use of the devices between students, increased direction of attention to social interactions (while using the device together with a peer), and lack of possibilities to proceed in line with one's individual learning processes.

In Study II, however, it was found that frequent use of digital learning materials had a more negative effect on learning outcomes at high (vs. low) levels of availability of digital learning device at school. Hence, the negative effect of digital learning materials on learning outcomes may not be accounted by low levels of digital device at school. Nevertheless, at the beginning of the 2010s, even more than 90% of the Finnish students were in highly digitally equipped schools (Wastiau et al., 2013). Hence, in

Finland, the availability of digital devices appears to be very high that may also explain the findings. In general, one-to-one laptop availability is found to be related to better learning outcomes than a lower availability of laptops (Bebell & O'Dwyer, 2010; Dunleavy et al., 2007), although some inconclusive findings also exist (Shapley et al., 2010; Suh et al., 2010).

5.1.5 Self-directed practices and open school environments

The results may also be explained by broader differences in school environments of teacher-directed vs. self-directed learning practices. That is, in order to fully implement self-directed learning practices (such as group work, group discussions, hands-on activities, experimental projects, or interactive games), new types of school environments are required. In some Finnish schools, the implementation of self-directed learning practices has resulted in building "open learning environments": traditional classrooms have been replaced by open learning spaces; stable groupings of students into classes have been replaced by changing combinations of students; and single school subjects have been combined into multi-disciplinary lessons. Overall, in some schools, these changes have resulted in less structured school days with lower number of routines and more changing relationships with peers and teachers.

To date, research evidence has shown that the instability of relationships and environments has adverse effects on children's and adolescents' psychological development and educational achievements. Specifically, instability of relationships between children or adolescents is related to, for example, higher loneliness and aggression, weaker school performance, and weaker adaptation during educational transitions (e.g. from elementary school to upper secondary school) (Poulin & Chan, 2010). Further, a close and stable teacher-student relationship is related to students' higher academic achievement (Hernández et al., 2017) and lower aggression (Rucinski et al, 2018). Further, a low quality of dyadic teacher-student relationship cannot be compensated by overall emotional support at school (Rucinski et al, 2018). Also, the unstability of school structures is related to increased risk for victimization of bullying in new students (Rambaran et al., 2019).

Importantly, a review stated that, over several decades, distraction due to experienced noise levels have been consistently reported in open classrooms when compared to traditional classrooms (Shield et al., 2010). High experienced noise levels, in turn, are associated with a wide variety of adverse consequences: for example, physiological stress reactions, fatigue, raised blood pressure, elevated epinephrine levels, and headache (Evans & Johnson, 2000; Gunnarsson, 2007; Standfeld & Matheson, 2003; Wålinder et al., 2007), lower level of school motivation (Evans & Johnson, 2000), and impaired reading comprehension and memory (Standfeld & Matheson, 2003).

Students with risky backgrounds or mild neurological or psychiatric symptomatology may experience open spaces, increased noise levels, and instability of social relationships and physical spaces as particularly stressful. Increased stress levels and feelings of unsafety, in turn, are related to lowed academic achievements and impaired functioning of such brain regions that are related to learning and memory (e.g. Lacoe, 2016; Rao & Raju, 2000). Moreover, in stressful environments, the neurological or psychiatric symptoms commonly become intensified. For example. anxiety-prone children may have more evident internalizing behavior (Findlay et al., 2009), children with ADHD symptoms may have disruptive beharior (Hampel et al., 2008), and children with autism-spectrum symptoms have more frequent stereotypic behavior (Attwood, 2006).

5.2 EARLY EDUCATION AND CARE AND LEARNING OUTCOMES

Study III investigated the association of participation in ECEC with learning outcomes at 15 years of age in Finland. In any learning domain (i.e. scientific literacy, mathematical literacy, reading literacy, or collaborative problem-solving), students who had only participated in preschool (at 6 years of age) did not differ from (1) students who had participated in preschool and started in ECEC at 3-5 years of age or (2) students who had participated in preschool and started in ECEC before 3 years of age. As additional analyses, child's starting age in ECEC was treated as unclassified variable. Students who had participated in preschool did not differ in any outcome domain from students who had started in ECEC at any other age between 1-5 years. All these associations were controlled for age, gender, and parental socioeconomic status. Moreover, at a trend level, it was found that the impact of participation in ECEC before preschool was slightly more positive for offspring of parents with high (vs. low) socioeconomic status.

Overall, our findings are in accordance with previous research. That is, a number of previous studies has indicated that the positive impact of ECEC on cognitive achievements may be short-term and not to endure into adolescence or adulthood (Belsky et al., 2007; Burger, 2010; Colwell et al., 2001; Downer & Pianta, 2006; Esping-Andersen et al., 2012;

Han et al., 2001; Magnuson et al., 2007; Votruba-Drzal et al., 2008). Thus, it may be that participation in ECEC promotes child's school readiness, rather than child's cognitive abilities per se. For example, participation in ECEC is predicts higher adjustment to school routines (Andersson, 1996) and better communicational skills (Connell & Prinz, 2002). Additionally, participation in ECEC is related to higher resistance against infections during the elementary school years (e.g. Côté et al., 2010). Taken together, attendance to ECEC may enhance child's adaptation to the classroom environment that, in turn, improves child's learning achievements during the first school year.

Our results suggested that participation in ECEC may be slightly more beneficial for children coming from privileged (vs. less privileged) family backgrounds. This may be explained by the socioemotional qualities that are required from children to successfully adapt to ECEC environments (e.g. Datler et al., 2012). That is, children are required abilities to express negative emotions to caregivers and receive emotional support from them, a sufficient level of social and self-regulation skills, ability to attach securely to caretakers, and to take part in on-going group activities (Ahnert et al., 2004; Datler et al., 2012; Howes & Smith, 1995). Among children coming from privileged families, these qualities have more likely been developed (e.g. Bradley & Corwyn, 2012). Hence, it may be that children coming from families with high socioeconomic status have better abilities to adapt to ECEC environments.

When considering international research evidence, some studies have found that family background does not modify the impact of ECEC on children's language skills, math skills, or memory skills (NICHD, 1998, 2002c, 2005; Ruzek et al., 2014; Vandell et al., 2010; Votruba-Drzal et al., 2010). On the contrary, other studies have suggested that ECEC can have more positive effects on cognitive outcomes among children with disadvantaged family backgrounds (Apps et al., 2013; Geoffroy et al., 2007; Magnuson et al., 2007; Melhuish et al., 2008; Peisner-Feinberg et al., 2001; Votruba-Drzal et al., 2013).

A likely explanation for the heterogeneous findings may lie in country-specific differences of ECEC and health care systems. That is, it appears that participation in ECEC has a stronger "compensatory" impact on children's development in extremely disadvantaged families (i.e. lack of food, apartment, and health care) but not necessarily in low-SES families of well-developed countries.

In many countries, offspring of low-SES families have a wide array of risk factors that may potentially affect their development adversely. For example, children of low-SES families have fewer pedagogical and recreational materials available, lack of regular meals, weaker access to health care services, lower level of hygiene, higher risk for impaired immune system functioning (e.g. Bradley & Corwyn, 2002; Bradley & Whiteside-Mansell, 1997; Crooks et al., 1995; Guo & Harris, 2000; Korenman & Miller, 1997; Scholer et al., 1999). In this kind of circumstances, participation in ECEC may likely compensate at least some of the adverse effects of the scarce environment.

In modern societies like Finland, in turn, the situation is very different. That is, all the Finnish children independently of parental SES have access to public health care services. Further, there are a variety of hobby clubs that are provided with children coming from risky backgrounds. Moreover, in Finland, the general level of hygiene is very high (e.g. WHO, 2010). Furthermore, maternity care is used by almost whole population of the Finnish pregnant women, regardless of socioeconomic factors (Official Statistics of Finland, 2017). Consequently, the Finnish children of low-SES families may likely live in much more favorable circumstances for development than children of low-SES families in some less-developed countries.

5.3 METHODOLOGICAL CONSIDERATIONS

5.3.1 Limitations

In the present study, there were some methodological limitations that are necessary to take into consideration.

General limitations related to the PISA datasets. Originally, the PISA data has been developed to investigate differences between countries (OECD, 2014, 2017a). The PISA datasets, nevertheless, have also been used in within-country studies widely (e.g. Kaya & Elster, 2018; Tømte & Hatlevik, 2011; Åström & Karlsson, 2007). Moreover, as in any large dataset, the results of statistical analyses conducted using the PISA datasets cannot be generalized to individual students (Nissinen, Rautopuro & Puhakka, 2018). Hence, the results provide evidence only about population-level associations. Nevertheless, when investigating the impact of various self-directed teaching practices, there have been a great number of case studies (e.g. Kazempour, 2009) as well as studies with very small samples (Creutzfeldt et al., 2012; Nishikawa & Jaeger, 2011; Pennala et al., 2014). Consequently, the aim of this dissertation was to investigate the impact of educational practices at a wider population level.

Moreover, the PISA datasets are cross-sectional by research design. Hence, the datasets cannot provide evidence about causal or temporal associations between the study variables (Nissinen, Rautopuro & Puhakka, 2018), for example, between students' psychosocial risk factors, teaching practices, and learning outcomes. On the basis of previous evidence, the associations between teaching practices and some types of students' behaviors may be bidirectional. Specifically, on one hand, low school achievements or low family SES may influence the effect of self-directed teaching practices on learning outcomes (Connor, Morrison, & Katch, 2004; Kirschner et al., 2006; Von Secker & Lissitz, 1999; Zohar & Dori, 2003). On the other hand, it has also been suggested that frequent self-directed teaching practices may be linked with more frequent truancy behavior at school (Furtak & Kunter, 2012) and disturbances in socialization processes at school (National Research Council, 2007).

Additionally, in the PISA datasets, most factors have been evaluated using self-reports (see e.g. OECD, 2014, 2017a; Nissinen, Rautopuro & Puhakka, 2018). For example, immigrant status, truancy behavior at school, and repetition of a grade were evaluated with self-reports fulfilled by the students. Consequently, it is necessary to take into consideration that self-report questionnaires are susceptible to various biases such as social desirability bias (e.g. Fisher & Katz, 2000). Importantly, however, the results were highly similar across a variety of different background factors (e.g. family wealth, gender, and repetition of a grade). Hence, the results may not likely be fully explained by possible self-report biases. In the future, students' background factors could be assessed using more reliable methods such as teacher's or parent's responses or register-based information from the school.

Overall, it is necessary to keep in mind that there are a wide variety of factors associated with learning outcomes in the PISA datasets (Nissinen, Rautopuro & Puhakka, 2018). For example, students' school motivation, attitudes and commitment to school work, social relationships, and leisure activities are known to be related to learning outcomes in the PISA datasets (Nissinen, Rautopuro & Puhakka, 2018). Consequently, pedagogical practices such as self-directed practices or use of digital learning materials explain only a relatively small part of the variance in learning outcomes. Hence, the explanatory power of pedagogical practices on learning outcomes should not be overestimated.

Moreover, the findings obtained in PISA datasets cannot be directly interpreted as indicators of various school curricula (Nissinen, Rautopuro & Puhakka, 2018). The PISA datasets do not measure school curricula and, further, it takes several years before any influences of school curricula reforms can be obtained in the PISA datasets (Nissinen, Rautopuro & Puhakka, 2018).

Assessment of teaching practices. The frequencies of various teaching practices were evaluated with self-report questionnaires fulfilled by students. Hence, the frequency of self-directed and teacher-directed practices are susceptible to assessment bias. The use of self-reports, however, has also strengths. Specifically, there is evidence that students coming from different backgrounds have tendency to use digital technologies in different ways (Andrews, 2008; Downes, 2002; Lee, 2005; Salemink et al., 2017; Tandon et al., 2012; Volman & van Eck, 2001). Further, in Finnish schools, students are commonly provided with freedom with regard to working strategies (i.e. whether they would like to utilize digital technologies or other strategies). Hence, there may exist variation in frequency of various teaching practices between single students within a class. Especially in large classrooms, teachers might not be able to provide reliable estimates about, for example, the frequency of digital technologies of each student.

Furthermore, the PISA datasets did not provide possibilities to conduct exact investigations whether different durations or different applications of digital learning materials could have different effects on learning outcomes. Nevertheless, there are a number of previous studies that have focused on only one or two specific sorts of digital technologies. Moreover, it has been common in the previous studies that the use of ICT at school has been very carefully adjusted with regard to duration, frequency, device, and applications (Chen & Li, 2010; Ronimus et al., 2014; Lan et al., 2010; Liu et al., 2009). Along with this, critique has been expressed that the "stylized" measurements may mitigate the ecological validity of the findings to practical school environments (e.g. Jacobsen & Forste, 2011). Hence, the primary aim of the current study was to investigate the impact of ICT use on learning outcomes at practical school environments without very careful laboratory-like adjustments.

Assessment of participation in ECEC. Participation in ECEC was assessed retrospectively in 2015 using questionnaires, i.e. without reliable register-based information. Hence, it could not be excluded the possibility of recall bias related to participation in ECEC. It is necessary to take into consideration, however, that several previous studies have evaluated exposure to ECEC with even more indirectly, for example, via the number of maternal employment months (e.g. Kosonen & Huttunen, 2018). Overall, future studies could measure exposure to ECEC using several sources of information (e.g. register-based information combined with parent's responses).

Further, the PISA datasets did not provide possibilities to investigate effect of the quality of ECEC. For example, it was not assessed whether students had received full-time or part-time ECEC. Previous studies have shown that full-time participation in ECEC may mitigate some positive effects of ECEC on child development (Nomaguchi et al., 2006). For example, full-day participation in ECEC is related to weaker school readiness (Brooks-Gunn et al., 2002), challenges in attachment to mother (NICHD, 1997), and higher risk for adverse changes in immune system and externalizing behavior (Gregg et al., 2003). Thus, in the future, it is necessary to investigate whether full-day vs. half-day participation in ECEC are differentially associated with child's psychological development in Finland.

Also, parental socioeconomic factors (i.e. the index of ESCS) were evaluated in 2015, not in participants' childhood. Thus, in Study III (study about ECEC), it was not possible to investigate whether childhood family SES modifies the association between ECEC and learning outcomes. In some families, the elements of the index of ESCS may have changed between students' early childhood and teenage years. Nevertheless, the stability of the socioeconomic factors is known to be high in adulthood. Moreover, the index of ESCS consisted of parents' occupational status, educational level, and family wealth, and this multidimensional composition of the index was used in order to increase its reliability and stability over years.

Assessment of learning outcomes. Cognitive learning outcomes (i.e. mathematical literacy, scientific literacy, reading literacy, and collaborative problem-solving) were assessed using computer-based tests. Thus, students' skills in using digital technologies may potentially have confounded the performance in cognitive test items. Nevertheless, when implementing the PISA 2015 tests, much effort was done in order to minimize the amount of computer skills needed for conducting the test items (OECD, 2017b). Further, students had possibilities to practice the computer-based items and different response formats before completing the test items (OECD, 2017b). Overall, it has been statistically estimated that the potential confounding impact of students' ICT skills on the test performance has been minor (OECD, 2017a). Finally, in this dissertation, the effect of ICT use at school with cognitive learning outcomes remained after controlling for students' perceived competence with ICT use.

Finally, data was available on self-directed learning practices in mathematics and science lessons. Hence, our results cannot be directly generalized to other school disciplines such as reading skills. Several self-directed practices, however, were originally developed to be used in mathematics lessons. Moreover, there is evidence that the influence of teacher-directed instruction may be more positive in reading lessons than mathematics lessons (e.g. Hattie, 2009). Hence, this tentatively suggests that frequent self-directed practices may potentially have a less positive effect on learning in some other subjects than mathematics.

5.3.2 Strengths

This study had a variety of substantial strengths. Firstly, there were comparatively large samples (N=5660, 5037, and 4634 in Studies I–III, respectively) that were approximately representative of the Finnish population of 15-year-old students. Hence, the results can probably be generalized nation-widely to various districts of Finland. To the best of our knowledge, there has been no other population-based wide datasets than the PISA datasets that provide such representative samples. Previously, several studies about teaching practices have included samples consisting of only a few classes (e.g. Castellar et al., 2014; Chiu et al., 2013; Edwards et al., 2013) or even less than 10 students in study groups (Creutzfeldt et al., 2012; Nishikawa & Jaeger, 2011; Pennala et al., 2014). Further, several previous studies have included biased samples: for example, students who own appropriate device (Basoklu & Akdemir, 2010) or more digitally-interested and digitally-capable individuals than on average (Bruce-Low et al., 2013).

Secondly, cognitive learning outcomes were evaluated with internationally standardized and objective tests. Hence, the learning outcomes were not susceptible to rating bias or unreliability of test items. Most previous studies have used comparatively short and unstandardized measures of learning outcomes: for example, a short set of questions about medieval Amsterdam (Rondon et al., 2013) or a short questionnaire about head and neck anatomy (Rondon et al., 2013). Additionally, the PISA datasets included broad outcomes such as mathematical literacy, reading literacy, scientific literacy, and collaborative problem-solving. This is contrary to a variety of previous studies where the tests have measured knowledge in only a very narrow domain such as computer knowledge or sexual coercion (e.g. Appel, 2012; Hung et al., 2013; Hung et al., 2013; Papastergiou, 2009).

Furthermore, several potential confounding factors could be taken into consideration: for example, age, gender, the index of ESCS, students' perceived ICT competence, and availability of ICT at school. This is a substantial strength because there is evidence that ICT use, for example, is affected by sociodemographic factors such as family SES (Andrews, 2008; Downes, 2002; Lee, 2005; Tandon et al., 2012), social or ethnic background (Volman & van Eck, 2001), or living area (urban vs. rural) (Salemink et al., 2017). In most previous studies about teaching practices, however, there have been no control variables (e.g. Ahmed & Parsons, 2013; Huang et al., 2010). Further, this dissertation investigated a variety of different risk factors: immigrant status, truancy behavior at school, repetition of a grade, single-parent family, and socioeconomic factors. Hence, the results can be generalized to a variety of different risk groups.

In the PISA datasets, the values of learning outcomes include regression coefficients, instead of absolute obtained test scores. Moreover, the datasets include a multi-level structure with single students, classes, and schools. Hence, it has been emphasized that the analysis of PISA datasets requires relatively complicated statistica analyses (Nissinen, Rautopuro & Puhakka, 2018). Consequently, it was used structural equation models that can estimate the error terms more precisely than e.g. regression analyses in such datasets like PISA. Moreover, the structural equation models of Studies I–III had excellent statistical goodness-of-fit indices. In several previous studies, statistical analyses have consisted of regression analyses (e.g. Fertig & Schmidt, 2002; Rangvid, 2008). Further, a number of previous studies investigating teaching practices have included only descriptive reports or qualitative studies without statistical testing.

The PISA datasets included several different types of measures: for example, computer-based tests and questionnaires. Hence, the findings of this dissertation may not be explained by the common methods bias (Gorrell et al., 2011; Podsakoff et al., 2003) that is typical in studies using only one type of measure.

All the studies were conducted using the Finnish PISA datasets. Finland provides a particularly fruitful environment to investigate the association of ECEC with learning outcomes. Firstly, in Finland, there are legislative guidelines for pedagogical and learning goals and caregiver-child ratios in all child care centers (Early Childhood Education (ECE) Legislation, 1973). Thus, this increases the level of homogeneity in the quality of ECEC in different child care centers. Secondly, there are academic-level educational programs for kindergarten teachers. Hence, the level of pedagogical knowledge is very similar between single caregivers in different ECEC environments.

Finally, the Finnish schools provide an advantageous environment for examining the effects of self-directed learning practices. Specifically, the rate of self-directed teaching methods has been increased from the beginning of the 2000s onwards in Finland (e.g. Hurmerinta & Vitikka, 2011). For example, already in the year 2004 and 2008 curricula, there are recommendations about promoting students' self-directedness, students' own learning projects, and students' responsibility for their learning processes and goals (The Finnish National Agency for Education, 2004, 2008). Additionally, the Finnish national curriculum does not define teaching practices very strictly but rather enables teachers' freedom and autonomy (The Finnish National Agency for Education, 2016). This results in variance of teaching practices between schools and classes that is necessary to conduct any investigations.

6 CONCLUSIONS

6.1 MAIN FINDINGS

In conclusion, the results suggest that frequent use of self-directed learning practices and frequent use of digital learning materials may be related to students' weaker learning outcomes in several knowledge domains at 15 years of age. Instead, frequenct teacher-directed practices were found to be related to students' higher learning outcomes. Moreover, the results indicate that frequent use of self-directed learning practices or digital learning materials may have more adverse effects on learning outcomes in students with (vs. without) risky background factors. Consequently, frequent use of self-directed learning practices or digital learning materials may increase inequality in learning outcomes between students coming from different backgrounds.

Additionally, this dissertation indicates that participation in ECEC before preschool (i.e. before the age of 6 years) may not be associated with learning outcomes in reading, mathematics, sciences, or collaborative problem-solving at 15 years of age. Further, no evidence was found that participation in ECEC could act as a "compensatory" factor for students coming from less privileged socioeconomic family backgrounds. Instead, at a trend level, the impact of participation in ECEC before preschool was slightly more positive for offspring of parents with high (vs. low) socioeconomic status.

Taken together, the results of this dissertation indicate that some educational practices *within* the school system may increase inequality between students coming from different backgrounds.

6.2 PRACTICAL IMPLICATIONS

6.2.1 Self-directed learning practices at school

Consideration of age and risk factors. On the basis of our results and previous research evidence, it is crucial to take into consideration students' age and risky background factors when selecting appropriate learning practices. That is, young students and students with risk factors are likely to need a higher amount of teacher's guidance and instruction and a lower amount of self-directed practices. In practice, those students should not be given learning tasks that require a high amount of independent work. Further, teacher could provide guidance in learning goals, schedule of school work, and learning strategies (e.g. setting interval goals).

Consequences of self-directed practices: considering the whole picture. When planning learning practices, it is necessary to take into consideration all the consequences of self-directed practices. In some students, self-directed practices are related to higher motivation, higher well-being at school, and more pleasant feelings during lessons (Guthrie & Wigfield, 2000; Lea et al., 2003; Randler & Bogner, 2006; Schaal & Bogner, 2005; Sturm & Bogner, 2008). Among other students (especially students belonging to risk groups), in turn, self-directed practices may be linked to more frequent misbehavior, weaker sense of security, and disturbances in socialization processes at school (Furtak & Kunter, 2012; Kim & Davies, 2014; National Research Council, 2007). When aiming to understand the inconclusive findings, it is necessary to take into consideration that engagement and burnout, for example, are not mutually excluding feelings but can be evident within a same student (Salmela-Aro, 2016). In Finland, it has been found that Finnish adolescents become more anxious and overwhelmed at school and also regard school as less valuable from 9th to 11th grade (Wang et al., 2015). Among teachers, in turn, frequent student-oriented learning practices may be related to, for example, excessive time consumption for preparating lessons (Lamagna & Selim, 2005; Sturm & Bogner, 2008: Angeli, 2002), higher frustration, and more frequent need for a break (Furtak & Kunter, 2012). Teacher-student relationships with prolonger conflicts are reported to be one of the main reasons for teachers' burnout (Pyhältö et al., 2011).

Role of multi-disciplinary research evidence. When planning school curricula and learning practices, it should be firmly based on empirical research evidence. Further, it is necessary to take into consideration multi-disciplinary evidence including e.g. pedagogical, psychological, neuroscientific, and psychiatric research findings. As has been emphasized previously (e.g. Cobern et al., 2010; Gao et al., 2014; Handelsman et al. 2004; Sykes et al., 2010), teaching methods should be carefully investigated and demonstrated to facilitate efficient learning, before the methods can be implemented in practice.

Phase of learning process. When selecting learning methods, it is necessary to identify the phase of learning process: whether the goal is to increase basic content knowledge, applying skills, procedural abilities etc. To date, research evidence has shown that self-directed practices are less efficient in the learning of basic content knowledge than applying or experimental skills (e.g. Kirschner et al., 2006; Mayer, 2004). Hence, self-directed practices (e.g. hands-on activities, interactive games, experimental projects) could be used after the acquisition of basic content knowledge and when aiming to enhance, for example, application skills.

Aims to promote the development of self-directedness. Self-control is shown to be more strongly influenced by genetic than environmental factors (Willems et al., 2019). The estimates of heritability of self-control have been varying between approximately 80% to "almost exclusive" heritability (Beaver et al., 2013; Coyne & Wright, 2014). Importantly, although genetic influences are clearly visible already in preschoolers (e.g. Stin et al., 2005), the influence of genetic factors on self-directedness is especially significant between the age of 12-16 years (Anokhin et al., 2017). Consequently, the role of the genetic contributions on self-directedness is incontrovertible.

Nevertheless, to a limited degree, environmental factors can influence the development of self-directedness. Research evidence has identified several efficient ways to promote children's self-directedness and related skills. A summary of the self-directedness-promoting practices can be seen in Table 16.

Table 16. A summary of practical ways to promote young students' self-directedness and related skills at school environments.

Teacher-student relationship

- Stable and reliable teacher-student relationship
- Teacher's frequent screening and guidance
- Verbal reminders of appropriate behavior in different situations
- Personal counseling with behavior (not merely general guidelines or counseling in front of other students)
- Realistic and clear feedback (both positive and negative) in a constructive and encouraging way
- An authoritative status of the teacher and effective discipline
- Slight changes in instruction: e.g. asking the student to "wait a little" in various practical situations or "stop and think" –exercises
- Teaching emotion regulation skills: e.g. stories about children with self-control problems and reflection of the situations

Qualities of physical environment

- Stability of working spaces and classrooms
- Restrictions of physical spaces available for learning (e.g. only in classroom, not anywhere within the school)
- Classrooms without extensive equipments
- Visual reminders of appropriate behavior on the wall of the classroom
- Prevention of excessive noise and visual or auditory stimuli at school
- Promoting feelings of safety and low levels of stress in the classroom

Practices in school work

- Clear and regular daily routines and rules
- Clear schedule of school work that is described to students beforehand
- Delayed rewards: demanding more effort before reward time after time
- Restrictions to one's self-interests: completing also tasks that do not arouse positive feelings or pleasure

Based on e.g. Berkman et al., 2012; Diamond & Lee; McClelland et al., 2007; Strayhorn, 2002b.

6.2.2 Use of digital learning materials at school

Not a goal in itself but a means toward higher-level goals. Our findings and previous evidence suggest that there are risks related to frequent use of digital technologies at school: digital learning materials may not necessarily promote learning outcomes and may also increase inequality in learning outcomes between students coming from different backgrounds. Hence, the use of digital learning materials should not be regarded as a goal itself but a means toward other goals such as learning some content knowledge.

Practical issues. On the basis of previous research literature, the effectiveness of digital learning materials among young students can be enhanced with a variety of practical issues that are summarized in Table 17.

Table 17. A summary of the practical issues that should be taken into consideration when using digital learning materials among young students.

A) Optimal sensory qualities of the device preventing cognitive load

- The key contents of the learning topic should be repeated several times
- In the application, the learner should have the possibility to easily go back and repeat the previously presented contents
- The learning content on the screen should not be switching too fast (so that the learner has the possibility to sufficiently process new information and build coherent schemas before further information is provided)
- On the screen, the material should be presented in such a way that learner's attention is automatically directed to most crucial issues (e.g. key issues marked with a larger font or with a different colour)
- On the screen, there should be no unnecessary material that is not a part of the learning content and that is presented simultaneously with the learning material (e.g. no colourful pictures/animations capturing learner's attention and competing with the limited capacity of learner's working memory)
- There should be a strong compatibility between auditory and visual material (not voices and visual views presented in an asynchronized way)

B) Low self-directedness required from the learner

- For a major part, learning contents should be selected on behalf of the learner: the key contents could be presented automatically (without risk of skipping them)
- In the learning material, new information should be presented in a logical way from step to step: new information should be coherently built on learner's previous knowledge so that the learner can easily form coherent schemas of the learning material
- The learning material should start with basic content knowledge and, thereafter, proceed to applications (not vice versa)
- New information should be at one's zone of proximal development

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- The application could enhance learner's attention: for example, include automatic suggestions of breaks and remind of the suitable distance between learner's eyes and the device (in order to prevent visual fatigue)
- There could be mid-tests and post-tests in order to ensure that the learner has processed all the necessary information
- The application could provide feedback for the student: elaborate explanations of the topic at times of incorrect responses (instead of merely informing about the correct response)
- Teacher or some other adult could conduct regular screening in order to prevent use of the device for other purposes than the learning task (especially among students with high technical competencies)
- Teacher or some other adult could provide clear learning goals and realistic schedule for the student

C) A suitable physical environment for learning

- The physical environment should include low noise levels and as few as possible competing stimuli (e.g. social interactions with peers)
- Sufficient guidance with the technical use of digital learning material (so that it would not cause stress to the learner)
- There should be individual access to digital learning materials, in order to enable processing of the material in line with one's own needs (group-based digital materials include a variety of challenges for learning)
- Use of digital materials should be organized in such a way that it does not interfere with fellow students not using digital materials

Based on e.g. Collins, 2007; Douglas et al., 2012; Kalyuga et al., 2003; Kirschner, 2002; Linnell & Caparos, 2011; Lavie, 2010; Merchant et al., 2014; Van Merriënboer & Ayres, 2005.

Additional support for risk groups. Since students belonging to risk groups commonly have a higher risk for working memory overload and a lower level of self-directedness (Berger et al., 2013; Brown et al., 2009; Gathercole et al., 2006; Holler et al., 2014; Kerekes et al., 2013; Reiter et al., 2005: Rose & Ebmeier, 2006), they are likely to need additional guidance and support from teacher in the use of digital learning materials. Moreover, the special qualities of various risk groups could be taken into consideration. For example, among students with autism-spectrum symptoms, it is useful to form a regular routine of ICT use and to keep the device and applications as stable as possible. Moreover, among students with reading disorders, long sentences and complicated word structures on the screen could be avoided. Among individuals with low spatial abilities, it is beneficial to use spatially simplistic views, without complicated 3D viewpoints. Additionally, among students belonging to risk groups (e.g. students with depressive symptoms), it may be necessary to slow the speed of presentation of digital material, to have additional feedback and rewards in order to maintain motivation and attention, and to have longer or more frequent breaks during the learning process.

Realistic implementations. As can be seen from Table 15, previous research evidence suggests that a successful implementation of digital learning materials requires a variety of practical issues to be taken into consideration. This may cause substantial practical challenges especially in large classrooms with high student-teacher ratios. Hence, digital learning materials should be built so that they automatically include the elements of sections A and B (see Table 15) and the teacher can focus on organizing the physical environment in the classroom so that it promotes learning (section C elements, see Table 15).

Low reliability of self-experienced learning outcomes. There is evidence that students are prone to overestimate the effectiveness of ICT use and to underestimate working memory overload deriving from multi-tasking (Douglas et al., 2012; Wood et al., 2012). Moreover, in several studies, there have been contradictions between students' experienced learning and tested learning outcomes (e.g. McKenzie , 2013). Consequently, the use of digital technologies should not be modulated in line with students' experiences about their effectiveness.

Promotion of motivation. Importantly, previous evidence suggests that use of digital technologies may be promote motivation particularly at the beginning of the learning process and among students with low motivation or low academic self-esteem (Jang et al., 2016, Zhang et al., 2006; Young & Wang, 2014). For example, it has been stated that "digital technologies can be effective in increasing students' motivation whereas they have limitations in increasing student achievement" (Jang et al., 2016). Hence, digital technologies could be used as a tool to enhance motivation and interest toward the learning topic.

Additive vs. compensatory use of digital learning materials. Several previous studies have found that, in many cases, use of digital learning materials is related to weaker learning outcomes when compared to non-digital methods (i.e. when replacing some non-digital methods by digital methods) (e.g. Carter et al., 2017; Chiu et al., 2013; Douglas et al., 2012; Fried, 2008; Hembrooke et al., 2003; Jacobsen et al., 2011; Kang et al., 2012; McKenzie, 2013). However, there is evidence that use of digital learning materials enhances learning outcomes when provided as an additional learning intervention (Erhel & Jamet, 2013; Hayati et al., 2013; Riconscente, 2013). Hence, digital learning materials could be provided as additional material after the basic content knowledge has been acquired, in order to promote e.g. students' application skills of the learning topic.

6.2.3 Participation in early education and care

Political decisions should be evidence-based. In many societal discussions, it has been postulated that participation in ECEC "lays the foundation for success in later life" (Määttä & Uusiautti, 2012) and increases equality in later school achievements (e.g. Hiilamo et al., 2018; Salmi, 2012). Along with this, the Finnish government has decided to increase children's participation rate in ECEC (Ministry of Education and Culture, 2016). However, in line with a number of previous studies (e.g. Belsky et al., 2007; Colwell et al., 2001; Downer & Pianta, 2006; Magnuson et al., 2007), our results showed that participation in ECEC is not related to learning outcomes at 15 years of age and appears not to increase equality between students coming from different family backgfounds. Consequently, when making political decisions related to ECEC, the arguments should be based on empirical research evidence.

Tailored programs for children with risk factors. If aiming to increase equality in educational achievements between children coming from different backgrounds, ECEC with similar quality provided for the whole age cohort may not be the solution. Also, in our study, no evidence was found that participation in ECEC could act as a "compensatory" factor for students coming from less privileged socioeconomic family backgrounds. This is in line with previous evidence showing that children coming from risky backgrounds as well as very young children are shown to be especially susceptible to the quality of child care: to large peer groups (De Schipper et al., 2006; NICHD, 2000; Sagi et al., 2002) and to instability of caregivers (De Schipper et al., 2004, 2004b). Children coming from risk groups also have a higher risk for elevated cortisol levels at ECEC environments (Ahnert et al., 2004; Dettling et al., 1999; Geoffroy et al., 2006; Groeneveld et al., 2012; Legendre, 2003). Hence, it could be important to provide individually tailored day care arrangements for children coming from risky backgrounds and, in particular, efforts to increase those children's adaptation and well-being in ECEC environments.

Role of kindergarten teachers' education. Several studies have obtained no effect of caregiver's education on children's socioemotional or physical well-being or cognitive development in ECEC environments (e.g. De Schipper et al., 2004b; Mashburn et al., 2008). Also, a meta-analysis found that "specialized training [of caregivers] improves pedagogical competencies of caregivers" but the effects of training on children's development was not statistically significant (Fukkink & Lont, 2007). The findings may likely be explained by that even though educated caregivers have high pedagogical competencies, practical ECEC environments may not enable them to fully utilize their competencies due to large group sizes and a high child-caregiver ratios. Hence, if aiming to enhance the positive impact of kindergarten teacher's education on children's development, it may be necessary to conduct practical changes to group sizes and physical spaces.

Group sizes and stable caregiver-child relationships. In an international comparison, the Finnish child group sizes in ECEC environments appear to be close to international average. In Finland, according to the legislation, there are allowed to be at most 12 children below 3 years in a child group (max 4 children per caretaker) and at most 24 children aged 3–6-years in a child group (max 8 children per caretaker) in child-care centers. In the Netherlands, the child-adult ratios are practically identical to those in Finland (De Schipper et al., 2004). In Indiana, in turn, the guidelines recommend smaller group sizes than in Finland. Specifically, there can be at most 8 children below 1.5 years in a group; at most 10 for children aged between 1.5–3 years in a group; at most 20 for children aged 3 years in a group; and at most 24–30 children aged between 4–5 years in a group (Elicker et al., 2005). There is evidence, for example, that reducing child-caregiver ratio from 5:1 to 3:1 produces a significantly higher quality of caregiver-child interactions (De Schipper et al., 2006). Hence, if aiming to increase benefits of ECEC on children's development in Finland, the allowed group sizes and child-adult ratios should be lowered.

All developmental domains into consideration. When making political decisions related to children's participation in ECEC, it is necessary to consider the impact of ECEC on all domains of child's development. Specifically, there is evidence that participation in ECEC predicts short-term improvements in school achievements and school readiness but, additionally, also long-term increases in externalizing and aggressive behavior that endure into adolescence (Belsky, 2001, 2007; Magnuson et al., 2007; Network, 2003; NICHD, 2001, 2007, 2016; Vandell et al., 2010). Additionally, there is evidence that attendance to ECEC predicts atypical and increased cortisol and adrenaline levels in childhood and adolescence (Geoffroy et al., 2006; Gunnar et al., 2010; Roisman et al., 2009; Vermeer et al., 2006). Hence, if aiming to increase the rate of participation in ECEC, there should also be considerable efforts and investments to prevent potential adverse impacts of ECEC on children's development.

A wider variety of alternatives for child care arrangements. In Finland, societal discussion has mostly been focused on whether the rate of children participating in center-based care should be enhanced or not. Instead, much less discussion has received other alternative child care arrangements. For example, there could be more flexible possibilities to hire a caregiver at home, to take the child to family care, or to use part-time child care arrangements. Part-time arrangements could be more beneficial for children since during the first years of life full-time ECEC is shown to be related to weaker developmental outcomes (Brooks-Gunn et al., 2002; Gregg et al., 2003; NICHD, 1997; Nomaguchi et al., 2006).

Resources and support to home care. Overall, it is known that the quality of home care is much more crucial predictor than the quality of ECEC environments. In several studies, the effect sizes of home care qualities on children's development have been even two times larger than those of ECEC qualities (e.g. NICHD, 1998, 2000, 2002). Hence, political decisions could be made to promote the quality of home care in less privileged families.

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Appendix

Table A1. The regression coefficients (B) with 95% confidence intervals (CI) of structural equation models, when predicting cognitive learning outcomes by the age of entry into early education and care.

	Cognitive learning outcomes							
	Scientific literacy		Mathematical literacy		Reading literacy		Collaborative problem-solving	
	B	95% CI	B	95% CI	B	95% CI	B	95% CI
Age	14.72**	6.14; 23.30	10.91**	4.11; 17.72	15.16***	7.61; 22.71	16.61***	6.21; 23.26
Gender	−15.24***	−20.12; −10.35	−2.98	−6.85; 0.89	−41.27***	−45.59; −36.95	−45.69***	−19.98; −10.27
The index of ESCS	38.48***	35.10; 41.85	34.26***	31.56; 36.96	34.21***	31.22; 37.19	29.72***	34.89; 41.60
Early education and care (ECEC)								
ECEC started at 6 years of age[1]	–	–	–	–	–	–	–	–
ECEC started at 5 years of age	−3.66	−11.44; 4.12	0.89	−5.28; 7.07	−8.62*	−15.46; 1.77	−4.70	−12.24; 2.86
ECEC started at 4 years of age	−7.50	−15.45; 0.44	−2.12	−8.42; 4.19	−3.60	−10.60; 3.39	−2.64	−10.36; 5.07
ECEC started at 3 years of age	−0.93	−8.67; 6.82	2.57	−3.58; 8.71	1.54	−5.27; 8.35	−0.49	−8.00; 7.02
ECEC started at 2 years of age	4.98	−3.79; 13.75	8.48*	1.52; 15.43	5.82	−1.89; 13.54	3.98	−4.53; 12.49
ECEC started at 1 year of age	1.31	−10.36; 12.97	5.94	−3.31; 15.20	1.71	−8.55; 11.97	−1.28	−12.61; 10.04

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. [1]The reference group. $N = 4634$.