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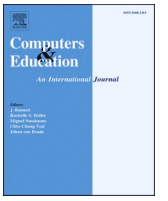

Early and late adopter effects between schools in a one-to-one computer initiative

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A B S T R A C T

Although there are numerous studies on the development of teachers' professional digital competence, only a few have studied the intermediate levels of the education system and its impact over time. A structural merger of three Norwegian municipalities allowed for a natural field experiment involving two school districts. In the present study, we explored potential differences in early and late adopter effects on teachers from school districts. Survey data were collected to assess teacher-level perceptions of organisational support and access to collaborative professional communities. Teachers also rated themselves according to the Technological, Pedagogical, and Content Knowledge (TPACK) framework for digital competence and answered questions to assess their level of student-centred teaching beliefs. The data were analysed using Structural Equation Model (SEM) to explore associations between study variables and patterns of differences between school districts. The results indicate that municipality- or school district-level initiatives have influenced the behaviour of school management and in the teacher community, and possibly result in a more student-centred teaching style in the classroom. The present paper adds new insights into how teachers and schools are influenced by the intermediate levels of the education system. The findings from our study may thus be of interest to researchers exploring the professional development of digital competence for teachers and schools. Moreover, as we highlight how school districts approach and support schools in the implementation of one-to-one coverage of digital devices in schools, we bring updated knowledge to this research field.

1. Introduction

Digital technology has surrounded every level of society, infusing nations, welfare systems, professional lives, well-being, and education. This ubiquitous presence of digital technology calls for skills, knowledge, and competence in how to approach, understand, act, and behave safely. Consequently, concepts such as digital mature organisations (Kampylis et al., 2015; Ifenthaler & Egloffstein, 2020), digital competence (Ilomäki & Lakkala, 2018; Zhao et al., 2021), and professional digital competence (Fernández-Batanero et al., 2020) have emerged. These concepts have been approached by both policymakers and researchers. In countries that are recognised as early adopters of digital technologies (Castañeda et al., 2021; OECD, 2020), educational institutions are crucial for providing future citizens with adequate skills, competencies, and knowledge (Fraillon et al., 2020; Arstorp, 2021). Various efforts have been put into place by national authorities to ensure digital competence for schools, their staff, and students (Zhao et al., 2021). Here, integrated digital competence for students in curricula for compulsory education, and professional digital competence for student teachers in curricula for teacher education are central (Erstad et al., 2021; McGarr et al., 2021; Starkey, 2020). Moreover, national authorities have earmarked funding for research and development of digital competence for students, teachers, and school leaders (Andreasen et al., 2022; Starkey et al., 2020), and enhanced overall digital infrastructures for educational institutions (Caena &

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Vuorikari, 2022; Islam & Grönlund, 2016). In addition to these government-led processes to foster digital competences and skills in education, edtech companies are increasingly gaining ground in national education systems by offering digital platforms, infrastructure, resources for education, and professional development courses related to their offerings (Tømte et al., 2020; Selwyn, 2021).

Nonetheless, the initiatives mentioned here can be framed as external and top-down initiatives towards school districts and schools. Moreover, in countries where school districts serve as school owners, their steering and governance capacity towards schools can be strong, since they hold the overall economic responsibility (Egloffstein & Ifenthaler, 2021). Being a school owner thus allows for governance of administration, provision of digital infrastructure, and offerings of professional pedagogical development of schools. These efforts may or may not be better aligned with the local needs of schools and their teachers (Kowch, 2021).

In Norway, compulsory education is guided by a national curriculum, most primary and secondary schools are public, and all schools are steered financially by their local authorities—that is, by local school districts (Tømte et al., 2020). In this paper, we present a study of one of these school districts that has implemented one-to-one coverage of digital devices. A key objective is to explore the school district approaches and fosters the professional development of digital competence for teachers in its schools, and how the schools and teachers respond to these efforts.

Initiatives that comprise the implementation of one-to-one coverage of digital devices for students and teachers in schools have been around for many years (Balankasat et al., 2013; Bocconi et al., 2013; Kampylis et al., 2015; Mulet et al., 2019); however, studies that have approached these initiatives over time or with a holistic perspective are scant, even though such approaches have been recommended by researchers (Islam & Grönlund, 2016; Pishtari, Sarmiento-Márquez, Tammets, & Aru, 2022). For example, some studies highlight the importance of a holistic approach when addressing professional development and pedagogical change among teachers as a joint effort and shared responsibility for all staff in schools (Backfisch et al., 2021; DuFour & Marzano, 2011; Ilomäki & Lakkala, 2018). Moreover, researchers suggest that the school leader plays a crucial role in ensuring professional development for staff and teachers and enhancing communities of practice among teachers (Dexter & Richardson, 2020; Lindqvist & Pettersson, 2019). In a systematic review that explored how various one-to-one initiatives have been studied, Pisthari and colleagues (2022) found that only a few studies had explored stakeholders' perspectives in the implementation of one-to-one coverage or adopted specific theoretical pedagogical frameworks to guide the research.

Further, less is known about how professional development is effectuated within the school districts and their schools during one-to-one coverage initiatives, and which initiatives foster professional digital competence among teachers from this intermediate level (Fernández-Batanero et al., 2020). Without a doubt, teachers' pedagogical style and beliefs may affect students' learning outcomes (Corredor & Olarte, 2019; Tondeur et al., 2017). A key takeaway is that resistance among teachers towards change is attributed to negative attitudes to the digitalisation of education and society, or to a low sense of mastery (Bond et al., 2019; Islam & Grönlund, 2016; Lindqvist & Pettersson, 2019). Researchers thus highlight the importance of organisational support and access to collaborative professional communities for competence development and changes in teacher practice (Fernández-Batanero et al., 2020; Ilomäki & Lakkala, 2018). Moreover, these efforts must be maintained over time and need to be approached as a *continuous* process to influence teachers' belief in and ability to integrate technology into their teaching (Caena & Vuokuari, 2022; Kafyulilo et al., 2016).

Using a natural quasi-experimental design (Leatherdale, 2019), we investigate adoption differences among teachers in a school district that employed various approaches towards one-to-one coverage of digital devices. The school district is a merger of three school districts, with the two smaller districts integrated into the larger in 2020 thus allowing two distinct samples of digital device adopters for this study. Prior to the merger, the larger district had deployed a comprehensive implementation initiative over a period of three years, including one-to-one coverage of digital devices for all students and teachers in primary and secondary schools. In addition, a systematic professional development approach for the development of digital competence of all teachers was included. Thus, we study the intermediary levels of the educational system, its' strategies, competence, and resources within the school district and school management levels.

2. Theoretic concepts and framing of the study

To expand the potential of pedagogical change provided by the implementation of one-to-one coverage of digital devices, we use Ertmer's theory on barriers to integration of technology model (1999), and Mishra and Koehler's theory of teachers' technological, pedagogical, and content competence, the technology, pedagogical, and content (TPACK) framework (Mishra & Koehler, 2008). We will explore how these theoretical concepts may help us to unpack teachers' professional development towards digital competence in one-to-one classrooms.

2.1. Barriers to the integration of the technology model and enablers of change

Ertmer's work on external (first-order) barriers and internal (second-order) barriers in the integration of digital technology in compulsory education is much cited by scholars and policymakers (Ertmer, 1999, 2005). External barriers (first-order) are obstacles that may hinder teachers from adopting digital technology, such as access to adequate technological hardware and software, institutional support, and competence development. Internal barriers (second-order) include inherent hindrances, such as knowledge, skills, and teacher beliefs. Teachers' beliefs about technology integration have been studied widely, since this type of barrier has been demonstrated to be strongly connected with teachers' actual classroom practice in the use of digital technology. Here, diverse types of beliefs have been studied, such as ability beliefs and value beliefs (Bowma et al., 2022; Xie, Nelson, Cheng, & Jiang, 2021). Moreover, diverse types of instruments and research methods related to second-order barriers have been applied to measure and explore various types of teachers' beliefs and motivations (Hatlevik, 2017). For example, teachers' self-efficacy to apply educational digital resources

in their teaching has been emphasised as an individual variable of importance (Voogt et al., 2013).

Based on their review of qualitative studies, Tondeur et al. (2017) maintained that the relationship between educational technological use and teacher beliefs is bidirectional. Educational beliefs are expected to influence not merely how digital resources are used, and for which educational purpose (Inan & Lowther, 2010; Miranda & Russell, 2012), but also that educational beliefs are shaped, and even transformed though extensive use of digital resources in teaching, resulting in more student-centred teaching beliefs (Matzen & Edmunds, 2007). These findings are highly relevant when schools have 1:1 coverage of digital devices, which provides teachers with multiple digital resources in their daily classroom-practices.

Ertmers' work has been further explored in various education contexts, for example, in distinct subject areas, such as English (Tanaka & Saito, 2021), art and crafts (Sevik & Tømte, 2022), and in newer areas of digital technologies, such as artificial intelligence (Wang & Cheng, 2021). To some extent, researchers have expanded the first-order and second-order barriers and added third- and fourth-order barriers, as in the case of studying teachers' integration of mobile technology instruction compared with technology-integrated instruction, suggesting barriers that relate to design thinking for mobile learning, and classroom management (Chen et al., 2022; Makki et al., 2018).

Nonetheless, only a few researchers have adapted Ertmers' model to explore schools and classrooms with one-to-one coverage of digital devices and to longitudinal studies. In a doctoral thesis including a survey of 98 teachers in middle school in the United States, the findings support previous research on first- and second-order barriers to technology integration, and the need for more longitudinal studies in middle school research and technology integration (Warren, 2020). Doron and Spektor-Levy (2019) conducted a longitudinal qualitative study involving seven teachers in two junior high schools to examine how they changed their views regarding the integration of students' personal laptops over three academic years in classrooms with one-to-one coverage. The key findings suggest that all teachers changed their views of teaching with technology during the years under study. However, their individual views differed from the start to the end of the actual period: whereas some changed from enthusiasm to disappointment, others changed in the opposite direction (Doron & Spektor-Levy, 2019). A similar finding was reported in a study covering a three-year implementation process of one-to-one coverage of digital devices in Norway (Tømte et al., 2020).

Further, the theoretical framing of various types of barriers to technology integration can be closely aligned with what is often framed as first- and second-order change within educational systems. This approach is, for example, observed in the work of Agélii Genlott et al. (2019), who studied the sustainability and dissemination processes of a validated pedagogical method. They elaborated on first- and second-order barriers that must be overcome to enable change, and they somehow equated the terms first- and second-order barriers to first- and second-order changes. Their study ran for five years and included surveys of 92 primary school teachers, and some key findings suggest that organised teacher development programmes can drive second-order changes, but this requires considerable, active, and sustained effort from leaders at both the school and district levels. Additional factors include immediate and extended social systems and the handling of diversity among teachers (Agélii Genlott et al., 2019). The extended social system entails social norms, opinion leaders and change agents. Certain factors at the immediate social system (the school level) were found to negatively relate to teachers' progression towards course objectives, including "that the principal endorses the use of the method beforehand, colleagues use the model beforehand, the use of the method is rewarded with salary increase, and the method is declared a standard method" (Agélii Genlott et al., 2019, p. 3030).

2.2. Technological and pedagogical content knowledge

The theory of teachers' first- and second-order barriers to integrating digital technology into their teaching has also been adopted to further explore findings identified using Mishra and Koehlers' TPACK framework (Koehler & Mishra, 2014; Mishra & Koehler, 2008). Over the years, studies have applied the TPACK framework to assess different aspects of teachers' professional technological use, ranging from purely technological knowledge (TK) to the ability to integrate technological knowledge with pedagogical practice and subject-specific content (TPCK; Koehler et al., 2014). Teacher self-efficacy to apply educational digital resources in their teaching has been emphasised as an individual variable of pivotal importance (Voogt et al., 2013). Numerous studies have applied the TPACK framework to assess different aspects of self-efficacy, including purely technological knowledge (TK) and the ability to integrate technological knowledge with pedagogical practice and subject-specific content (TPCK; Koehler et al., 2014). Both TK and TPCK are associated with teacher behaviour, such as pedagogical practices. Moreover, studies have indicated that both TK and TPCK are influenced by contextual factors at the school level, such as organisational support and professional community among colleagues, or at the teacher educator level (Tondeur et al., 2017). However, only a few studies have addressed the influence of the school district level.

2.3. Research questions

The purpose of the present study is to explore how school district digitalisation initiatives related to the implementation of one-to-one coverage of digital devices influence school-level support and collaborative professional communities and, as a result, impact teacher's professional digital competence. We aim to answer the following research questions.

1. How do teachers perceive external barriers, measured as organisational support and collaborative professional communities?
2. What are the associations between teachers' perceptions of external barriers and internal barriers related to the use of digital resources in teaching, measured as competence and teacher beliefs?

3. Are there differences in perceptions of external barriers and internal barriers between teachers from early- and late-adopter schools due to a merger of municipalities?

The three research questions are guided by theories of internal and external barriers towards the integration of digital technologies for teaching and learning, and further elaborated by a set of validated survey instruments. The remaining parts of the article include an outline of the research methods, its instruments, and analysis, followed by a presentation of the results, discussion, and conclusion.

3. Methods

3.1. Context

The present study was conducted within a municipality in Eastern Norway, which in 2017 involved a school district with 24 public primary and secondary schools. That year, one-to-one coverage of publicly financed portable digital devices (Chromebook) followed by an upgrade of technical infrastructure, including broadband capacity, was implemented in all schools. The one-to-one coverage was conducted as a stepwise approach, including professional competence development for all teachers, the formation of local resource teams at each school, and regular meetings with the school district programme office (Tømte et al., 2020). Due to a merger with two neighbouring municipalities in 2020, an additional 15 schools (containing 1st–10th grade) were included in the school district. Thus, the municipality currently includes three former municipalities that merged in 2020, each of which we label a stratum. Before the merger, the three municipalities (M1, M2, and M3) differed in several factors, such as size and number of schools, as shown in Table 1. As demonstrated in the table, the original municipality is conceptualised as an 'early adopter' of one-to-one coverage of digital devices, while the two municipalities that merged are here recognised as 'late adopters'.

The implementation of digital devices differed across the former municipalities before the merger. In M1, there was a one-to-one programme at all primary and secondary schools that had followed a step-by-step programme of implementation since 2017. The programme included competence development of all teachers, allocation of personal resources, and a robust plan for coordination (Tømte et al., 2020). In M2, there was also one-to-one coverage, but there were and were variations between which devices were used, both between and within schools. All schools had the allocation of personal resources, but only some teachers received courses or support in digital competence from their local municipalities. In M3, different devices were used in primary school and lower secondary schools, as well as between lower secondary schools. Much of the digital implementation and organisation was localised through at-school personnel who were given extra resources.

As of January 2020, a merger of the three municipalities was implemented, and schools from M2 and M3 were included in the one-on-one initiative initiated by M1. In the following analyses, respondents from M2 and M3 are combined to represent the "late adopters", and respondents from M1 are labelled "early adopters".

3.2. Study design

The structural merger of the municipalities allowed for a natural field experimental design consisting of two samples of teachers from early and late adopters. A quasi-experimental design, especially post-test only, does not allow causal inferences and is prone to individual-level bias due to confounding variables (Leatherdale, 2019). However, the digitalisation of the school system is pervasive and fast-paced, whereas one-to-one coverage initiatives are driven by municipalities and government policy, not researchers. A natural quasi-experimental design allowed us to explore the consequences of a one-to-one coverage initiative for two samples in a relatively similar context. Since the merger was decided during our study, cross-sectional post-test-only survey data were available for the sample in total.

3.3. Participants

During fall 2020, the schools were recruited, and a digital questionnaire was distributed to all teachers. The research project was reviewed by the Norwegian centre for research data, including collection of participants' consent. The data collection was terminated in February 2021. A total of N = 629 teachers from 37 schools completed the questionnaire, partially or completely, representing

Table 1
Overview of the three strata (former municipalities).

	M1 (Early adopters)	M2 (Late adopters)	M3 (Late adopters)
Number of residents	62,000	9500	23,000
Number of primary and secondary schools	25	5	10
Implementation of one-to-one coverage	In 2017, all schools in the school district were included.	In 2018, all schools in the school district were included	On-to-one coverage in local schools, not the entire school district.
Portable digital device	Only Chromebook	Schools could choose between iPad, PC and Chromebook	Schools could choose between iPad, PC and Chromebook
Program of implementation	Comprehensive school district level program incorporating all K–12 schools	School level programs locally at each school	School level programs locally at school who chose to implement one-to-one coverage

response rates of 61.5% and 66.0% among the early and late adopters, respectively. Among all responders, 65.0% of the teachers belonged to one of the 22 early-adopter schools, and 35.0% belonged to one of the 15 late-adopter schools. Due to the relatively high and equally high response rates across groups, and balance between the two groups on key variables (see section 3.6), we found no evidence that the skewness in the number of schools of each adopter type represent a skewness of different types of schools beyond the core study variables. Moreover, there was sufficiently high N for detecting misfit in structural equation modelling with reasonable assumptions of the population parameters (Wolf et al., 2013). We thus deemed further analyses appropriate.

3.4. Instruments

Following Ertmer's (1999) theoretical framework, the study captured one first-order barrier: teachers' perceptions of organisational support and collaborative professional communities at the local school level. Three second-order barriers were also captured: student-centred teaching beliefs, technological competence, and the competence to integrate technological understanding with content knowledge and pedagogical skills.

3.4.1. Organisational support and collaborative professional communities (OSC)

The teachers' perceptions of organisational support and access to collaborative professional communities were measured using a nine-item questionnaire labelled the organisational support and collaborative professional community (OSC) scale. The scale was derived using six items (A–F) obtained from the International Computer and Information Literacy Study (ICILS) 2019 survey and three (G–I) obtained from the Information and Computer Technology (ICT) School Monitor survey (Fjørtoft et al., 2019). The participants responded to the items according to a 5-category scale ranging from completely disagree to completely agree (see Appendix A; Table B).

3.4.2. Student-centred teaching beliefs (SCTB)

Teachers' practice regarding student-centred, that is, constructivist, teaching beliefs was assessed using the Student-centred Teaching Beliefs (SCTB) scale, previously validated on a sample of pre-service freshman and student teachers in the United States by Woolley et al. (2004), who distinguished between constructivist teaching beliefs and traditional teaching beliefs. The participants were presented with seven statements and asked to rate their level of agreement according to a 4-category agreement scale (see Appendix A, Table C).

3.4.3. Technological pedagogical content knowledge and technological knowledge

The teachers' self-reported technological knowledge (TK) and their ability to combine technological skills with pedagogical and content knowledge (TPCK) were measured using two subscales of the TPACK questionnaire developed by Schmidt et al. (2009) using a 4-category agreement scale. The teachers were asked to indicate the extent to which they agreed with a number of statements that referred to the technology dimensions (see Appendix A, Table D, and Table E).

3.5. Psychometric properties and statistical analysis

Single-group and multi-group confirmatory factor analyses (CFA) were used to investigate the instruments' assumptions of unidimensionality, measurement invariance across the early and late adopters, and scale reliability. For the CFA and structural equation models, the ordinal manifest variables were handled using weighted least squares with mean- and variance- (WLSMV) adjustment in Mplus 8.6 (Muthén & Muthén, 2021). WLSMV better handles deviations from distributional assumptions, as we have variables with data on only three categories (SCTB).

3.5.1. Unidimensionality

Model fit was judged using the commonly used fit criteria suggested by Marsh et al. (2005): a comparative fit index (CFI) and a Tucker–Lewis index (TLI) above 0.95, with a root-square mean error of approximation (RSMEA) below 0.08 and a standardised root mean-square residual (SRMR) below 0.10 qualify as adequate fit. We consider CFI above 0.95, RMSEA below 0.05 and SRMR below 0.05 as good fit. Moreover, a non-significant chi-square test of fit of the model to the data qualify as a very close fit. Standardised loadings below 0.5, standardised residuals for correlations above 0.10, and modification indices were investigated for elimination, but only briefly reported due to space constraints. Table 2 shows that the unidimensionality assumption was not rejected for any instrument, despite RMSEA being somewhat high for OSC[1] and TPCK.[2]

3.5.2. Measurement invariance

We investigated measurement invariance across early and late adopter groups—that is, whether the groups (early and late adopters) perceived and understood the items similarly—with a restrictive scalar model, a semi-restrictive metric model, and a less restrictive configural model. In the configural model, we tested the assumption that the same items loaded on the same factor in both

[1] Residual correlations between item 6 and three other items exceeded 0.1, but no clear theoretical justification arose for correlating these items. Improved fit could be obtained by splitting the items into their respective sources (see section 3.3.3), but the factor correlation would be near 1.

[2] No residual correlation exceeded 0.03, and no standardised loading were below 0.8.

Table 2
Unidimensional fit and scale reliability of instruments.

Label	*n*	*i*	χ^2	*df*	*p*	*CFI*	*TLI*	*RMSEA*	*LB*	*UB*	*SRMR*	α
SCTB	543	6	20.8	9	.014	.971	.951	.049	.021	.077	.036	.58
OSC	547	9	260.6	27	<.001	.951	.934	.126	.112	.140	.042	.87
TK	550	5	17.7	5	.003	.998	.996	.068	.035	.104	.014	.87
TPCK	549	4	12.6	2	.002	.998	.993	.098	.051	.153	.012	.84

groups. Note that loadings, thresholds, and scales could vary across groups. In the metric model, loadings were restricted across groups, whereas thresholds were allowed to vary. In the scalar model, we tested the assumption that factor loadings and thresholds were the same across both groups. Only when the scalar model holds can meaningful comparisons of factor means across groups be justified (Jin, 2019). To evaluate the extent to which the invariance assumption held, we investigated the model fit of each model and compared the fit of the more restrictive model with the fit of the less restrictive model. For the latter comparison, we used Jin's (2019) simulation-based recommendations for cut-off values in situations with ordinal data, a sample size of around 500, and assumed a small factor mean difference (≈0) and no cross-loadings. This suggests cut-off values for scalar invariance of ΔCFI ≤0.001, ΔTLI ≤0.001, and ΔRMSEA ≤0.005, or alternatively, a non-significant chi-square test between the metric and scalar models.

Table 3 shows that the scalar invariance assumption held—with even improvements in RMSEA and CFI and a stable SRMR—for SCTB, TK, and TPCK. Only for OSC was scalar invariance not fully supported, given the significant chi-square difference test, but all other indices indicated improvement in fit for the more restricted models. Hence, further modelling safely assumed sufficient measurement invariance across the two groups.

3.5.3. Scale reliability

We investigated measurement precision, or scale reliability, using McDonald's Ω, which is more precise with freely estimated factor loadings and generally recommended more than Cronbach's alpha (McDonald, 1999; Revelle & Zinbarg, 2008). Moreover, we scrutinised the total information curves per instrument to assess which sections of the measure contained the most information. Table 1 shows that scale reliability, as measured with Cronbach's alpha, was high for all but CTS. Measurement precision was for SCTB highest at the middle-low [–1, −0.5] and middle-high [0.3, 0.7]; for OSC highest at the broad middle range [–1.6, 1.4]; for TK highest at the very low [–2.1, −1.9], low [–0.9, −0.7], and high [0.8, 1.1]; and for TPCK highest at the low [–2.4, −1.5] and high [0.4, 1.3]. Together with a lack of support for a sum-score assumption, latent variable modelling is appropriate and warranted in subsequent analyses.

3.6. Characterising the two school district groups

Table 4 shows that there were generally few differences between the early and late adaptors regarding response rate, gender balance, years of experience, and reference class grade. All differences between the samples were related to the years of access to, and frequency of use of, the tablet, and size of the school.

In the entire sample, 38% of the teachers worked in grades 1–4, 34% worked in grades 5–7, and 28% worked in grades 8–10. A majority (78%) were female. In total, 11% of the teachers were "resource teachers" in digitalisation, that is, teachers with allocated time and responsibility for improving the digital competence at each school. Most teachers (58.5%) had more than 12 years of experience as teachers, which is further explored in the Results section.

4. Results

4.1. Latent relations among constructs in entire sample

Fig. 1 shows the correlation matrix for the four latent variables in the entire sample. TK and TPCK correlated to a large extent (.75; Cohen, 1988), but not unitary a finding that resonates with earlier studies of the two as part of the TPACK framework. TPCK and SCTB correlated to an almost-large extent (0.48), which reflects the constructs' links to pedagogy. However, this association also implies that teachers knowledgeable in TPCK tend to emphasise a constructivist style. OSC had medium-sized correlations with both TK and TPCK. These relationships might reflect the higher organisational support useful for developing one's technology-oriented knowledge. Associations between SCTB and each of OSC and TK were small (0.17 and 0.21), but significant, and likely reflect the divide between pedagogical practice on one side and purely organisational and technological aspects on the other.

4.2. Differences in latent correlations and means across groups

The model fit summaries in Table 5 show that the overall fit of the model to the data was adequate, although a significant chi-square test indicated a rejected perfect fit to the data. All comparative fit indices (CFI, TLI, RMSEA, and SRMR) indicate an adequate fit. An investigation of the entire model's measurement invariance by sequentially increasing restrictions revealed that CFI was stable, TLI and RMSEA improved slightly, and SRMR worsened slightly. However, these changes were miniscule.

Continuing the analysis under the non-rejected assumption that the instruments, individually and collectively, worked similarly well across the two groups, we infer that some relationships differ substantially between the two groups. Fig. 2 displays the correlations

Table 3
Fit indices of measurement invariance models.

Label	Model	χ^2	*df*	*p*	*CFI*	*TLI*	*RMSEA*	*90%*	*CI*	*SRMR*
SCTB	Configural	40.92	18	.002	.943	.905	.068	[.041,	.096]	.050
SCTB	Metric	46.26	23	.003	.942	.925	.061	[.035,	.086]	.056
SCTB	Scalar	52.09	28	.004	.940	.936	.056	[.032,	.080]	.059
SCTB	Metric vs. configural	7.84	5	.165	.001	−.020	.007	[.006,	.010]	−.006
SCTB	Scalar vs. metric	6.84	5	.233	.002	−.011	.005	[.003,	.006]	−.003
OSC	Configural	326.67	54	<.001	.941	.921	.136	[.122,	.150]	.049
OSC	Metric	325.07	62	<.001	.943	.934	.125	[.111,	.138]	.051
OSC	Scalar	340.4	88	<.001	.945	.955	.102	[.091,	.114]	.052
OSC	Metric vs. configural	26.51	8	.001	−.002	−.013	.011	[.011,	.012]	−.002
OSC	Scalar vs. metric	54.73	26	.001	−.002	−.021	.023	[.020,	.024]	−.001
TK	Configural	23.67	10	.009	.998	.996	.070	[.034,	.108]	.017
TK	Metric	25.11	14	.034	.998	.998	.054	[.015,	.087]	.018
TK	Scalar	34.02	23	.065	.998	.999	.042	[.001,	.070]	.021
TK	Metric vs. configural	4.50	4	.342	<.001	−.002	.016	[.019,	.021]	−.001
TK	Scalar vs. metric	9.74	9	.372	<.001	−.001	.012	[.015,	.017]	−.003
TPCK	Configural	27.09	4	<.001	.995	.986	.145	[.096,	.199]	.017
TPCK	Metric	18.37	7	.010	.998	.996	.077	[.035,	.121]	.017
TPCK	Scalar	27.68	12	.006	.997	.997	.069	[.035,	.103]	.020
TPCK	Metric vs. configural	0.78	3	.853	−.003	−.010	.068	[.061,	.078]	<.001
TPCK	Scalar vs. metric	9.15	5	.103	.001	−.001	.008	[.001,	.018]	−.003

Table 4
Summary descriptives of teachers for manifest variables by school district group.

School district group	Late adaptors	Early adaptors	*p*
n	222	411	
Response rate (n/N)	66.0%	61.5%	
Teacher characteristics			
Female	79.6%	76.8%	.528
Years of experience			.537
0−5	15.1%	17.4%	
6−11	21.9%	25.8%	
12−18	24.5%	25.2%	
> 18	38.5%	31.7%	
Resource teacher	12.0%	10.7%	.057
Reference class characteristics			
Grade			.760
1−4	40.0%	39.4%	
5−7	33.1%	33.2%	
8−10	27.0%	27.5%	
Years with access to tablet (Chromebook)			<.001
<1	15.1%	10.7%	
1−2	58.0%	24.9%	
3−4	26.9%	64.5%	
Frequency of tablet use			.049
Once per week or less	5.3%	9.0%	
2–5 days per week	34.5%	27.2%	
Everyday	47.0%	44.6%	
Most lectures	13.3%	21.6%	
School characteristics			
Pupils in school			<.001
100–299	62.2%	22.1%	
>300	37.8%	77.9%	
Teacher responses per school *M* (*SD*)	19.6 (25.6)	25.7 (48.6)	.129

Note. *P* = Chi-square difference test (or *t*-test for years as teacher).

in each group, with the upper-left triangle showing the late adopter group and the lower-right triangle showing the early adopter group. Mean differences (early − late) are displayed on the diagonal. Only significant mean differences and correlations ($\alpha = .05$) are shown, and colour indicates strength. The small but significant relationships we found earlier for the whole sample between SCTB and OSC, TK, and TPCK seemed entirely dependent on school district group. The correlations between SCTB and TK and SCTB and TK were not different from zero in the late group, whereas they were slightly larger for the early group than for the entire sample. The SCTB-TPCK correlation was .13 lower in the late group than in the early group. Of these highlighted correlations, the SCTB-TK correlation was the only that was significantly different between the two groups at the critical value $\alpha = .05$ ($\Delta r = 0.234$, $SE = 0.09$, $p = .010$).

Fig. 1. *Latent Correlations Matrix.* All correlations are significant at the critical value α = 0.05.

Table 5
Fit indices of measurement invariance models.

Model	χ^2	*df*	*p*	*CFI*	*TLI*	*RMSEA*	*90%*	*CI*	*SRMR*
Single group	632.75	224	<.001	.969	.965	.057	[.052,	.063]	.060
Configural	904.39	448	<.001	.964	.959	.061	[.055,	.066]	.074
Metric	924.45	467	<.001	.964	.961	.060	[.054,	.065]	.075
Scalar	984.42	509	<.001	.962	.963	.058	[.053,	.064]	.076
Metric vs. configural	35.49	19	.012	<.001	−.002	.001	[.001,	.001]	−.001
Scalar vs. metric	79.51	42	<.001	.002	−.002	.002	[.001,	.001]	−.001

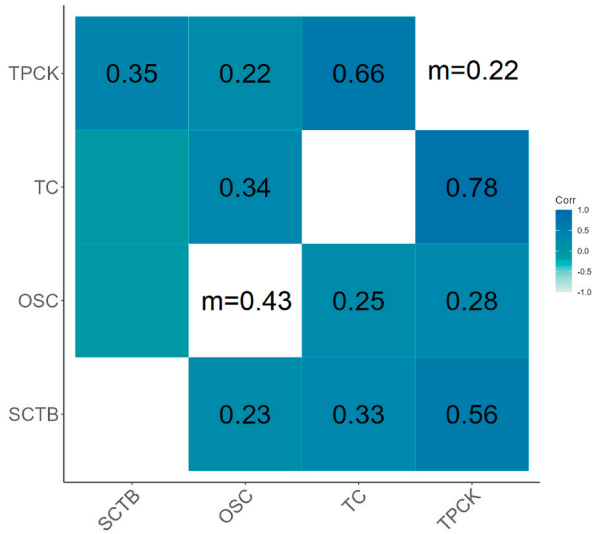

Fig. 2. *Correlations on the Off-Diagonals and Mean Differences in Favour of the Early Adopter Group (m) on the Diagonal.* The early adopter group is on the bottom-right triangle, and the late adopter group is on the upper-left. All in-text correlations and mean differences are significant at the critical value α = .05.

The diagonal in Fig. 2 show that the means, that is, the standardised estimates, in the early group were significantly higher for OSC ($b_{OSC} = 0.43$, $SE = 0.10$, $p < .001$, 95% CI [0.24, 0.63]) and TPCK ($b_{TPCK} = 0.22$, $SE = 0.11$, $p = .038$, 95% CI [0.01, 0.43]), and higher, but not significantly so for TK ($b_{TK} = 0.17$, $SE = 0.09$, $p = .075$, 95% CI [−0.02, 0.35]). There was no difference for SCTB ($b_{SCTB} =$

−0.07, $SE = 0.11$, $p = .501$, 95% CI [−0.29, 0.14]). In sum, OSC and TPCK were higher for the early group.

4.3. All variables included

Although the simple models above provided simple correlations for each group, there were still confounders and background variables worth investigating. We included the variables described in Section 4.1 as explanatory variables for each of the four outcomes while adjusting for the false discovery rate (Benjamini & Yekutieli, 2001). This model also had an adequate fit: χ^2 (*df*, *p*) = 1147.9 (623, p < .001), CFI = 0.947, TLI = 0.937, RMSEA = 0.04, SRMR = 0.059. From the parameters of this model (see Appendix F), we can infer four main points under the usual interpretation of everything else staying constant. First, among the mean differences in Fig. 2, the difference for OSC remained, and now increased ($b_{OSC} = 0.541$, $SE = 0.113$, $p < .001$, 95% CI [0.32, 0.76]). Second, resource teachers scored much higher than other teachers on OSC, TK, and TPCK. Third, more experienced teachers, and logically older teachers, had lower beliefs regarding their TK. Fourth, female teachers had higher beliefs regarding their TPCK than did males.

Late-adopter teachers who used Chromebooks for all lessons were higher on SCTB than those who used them at most every day. Early-adopter teachers who did the same were not higher on SCTB. Female early-adopter teachers were less satisfied with their organisational support than male early-adopter teachers. There were no such differences among the late adopters. Among the late adopters, those who used Chromebooks less frequently had lower TK than those who used them every day. There were no such differences among the early adopters.

5. Discussion

The purpose of the present study was to investigate how a school district initiative to implement one-to-one coverage influences teachers' perceptions of external and internal barriers to the use of digital resources in teaching. We posed three research questions, 1) How do teachers perceive external barriers, measured as organisational support and collaborative professional communities? 2) What are the associations between teachers' perceptions of external barriers and internal barriers related to the use of digital resources in teaching, measured as competence and teacher beliefs? And, 3) Are there differences in perceptions of external barriers and internal barriers between teachers from early- and late-adopter schools due to a merger of municipalities? Due to a merger of municipalities, we explored the data for differences between teachers in the early and late-adopter schools. Ertmer's distinction between external and internal barriers was applied to model the relationships between the latent variables using SEM analyses (Ertmer, 1999).

Overall, we found distinctive differences between teachers in the early- and late-adopter schools related to their perceptions of organisational support and collaborative professional communities at their local schools. Teachers in the early-adopter school rated the first-order enabler of collaboration with colleagues as better in the sense that they more frequently share digital teaching material, cooperate to improve the use of digital resources, and observe each other's use of digital resources in teaching. These activities can contribute to collaborative discourse, which is critical to the process of knowledge construction and sense-making (Lefstein et al., 2020), and to the development of competence on how to integrate digital resources with content knowledge and pedagogical skills (Koehler et al., 2014; Yeh et al., 2021).

As for managerial support, the differences are inconclusive. Teachers in the early-adopter schools rated the first-order enabler of sufficient time to plan instruction using digital resources as better than teachers in the late-adopter schools. The latter also rated access to peer guidance from the ICT coordinator as worse. However, there were no differences related to sufficient technical support for the maintenance of devices and sufficient opportunities for digital competence development. From the teachers' perspectives, first-order barriers typically materialise at the school level, especially in relation to the behaviour of colleagues and school management (Håkansson Lindqvist, 2019; Navaridas-Nalda et al., 2020). External barriers are multifaceted and multi-level, incorporating the school, the school district, and the national level (Kowch, 2021). Barriers related to technological infrastructure, technical support and economic resources are typically caused by school district- and municipality-level decisions, also labelled "stakeholders' commitment and support" according to the list of implementation challenges suggested by Islam & Grönlund (2016). These first-order barriers are often referred to as "basic" (Ertmer et al., 2012), but they are nonetheless a challenge when large-scale one-to-one coverage is implemented, especially in a context with a merger of municipalities and school districts. Three years after the implementation of one-to-one coverage in a Swedish school context, Lindqvist & Pettersson (2019) found that technical problems were still highlighted as a challenge by school leaders.

Our findings indicate that during the first two years of the implementation of the one-to-one coverage, a stronger collaborative professional community for the use of digital resources in teaching had evolved at the early-adopter schools compared to the late-adopter schools. Peer-to-peer learning took place in both unstructured and spontaneous situations, as well as during meetings and seminars at the local school and in networks across schools (Tømte et al., 2020). When the late adopters were merged into the school district two years later, they were given access to the same formal training resources and networks across schools. Both groups of teachers rated the opportunities to develop their competence in the use of digital resources as relatively sufficient, and the difference was non-significant.

According to Ertmer (1999), the reduction of first-order barriers is a necessary, albeit not sufficient, prerequisite for appropriate technology integration. The present study included a selection of second-order barriers that has been subject to extensive research: SCTB (Wooley, 2004), as well as TK and TPCK (Koehler et al., 2014). Given the apparent early adopter effect related to teachers' perceptions of organisational support and collaborative professional communities, the lack of a similar effect on internal barriers is somewhat unexpected. A study on early adopters during the first two years revealed that the use of digital resources in teaching varied considerably between teachers, and that professional development initiatives at the school and school district levels failed to narrow

the gap (Tømte et al., 2020).

The association between TK and TPCK was relatively strong for both groups of teachers in this study. This is in line with the tenets of the TPACK framework which describes the complex relationship between three basic components of knowledge; technology, pedagogy, and content (Mishra & Koehler, 2008). Empirical studies have found that TK and TPCK are closely related, but still distinct, and applicable across contexts (e.g. Koehler et al., 2014; Mishra & Koehler, 2008; Schmidt et al., 2009). However, the association between SCTB and TPCK was considerably stronger for teachers in the early-adopter schools compared to teachers in the late-adopter schools. This is also the case for the association between SCTB and TK, which was even stronger in the early adopter group. The latter findings might suggest that SCTB and TPACK reflect more constructivist attitudes to learning, which take time to acquire – though our design could not test this idea. For teachers in the early-adopter schools, these associations are in line with a growing body of research on the link between pedagogical beliefs and the educational use of digital resources (e.g., Tondeur et al., 2017, Bowmann et al., 2022). Moreover, the association between SCTB and organisational support and collaborative professional communities was statistically significant for teachers in the early-adopter school, and non-significant for teachers in the late-adopter schools.

The present study design allows for a closer investigation of the adaption process that took place following the implementation of one-to-one coverage. Our findings indicate that a school district initiative with a clear aim and a systematic implementation process influences the local school culture in terms of management support and collaborative discourse between teachers. Continuous attention to the challenges and possibilities inherent in one-to-one coverage of digital devices seems to influence the internal barriers of the teachers over time. The difference between early and late adopters could indicate that teachers in the early-adopter schools, to a larger extent, are past the process of adapting technology to a conventional teaching style and are developing a more SCTB (Islam & Grönlund, 2016). Further, we found clear positive associations between teachers' perceptions of organisational support and collaboration and a stronger SCTB, their technical competence, and their ability to integrate digital resources with content knowledge and pedagogical skills.

As demonstrated, the efforts provided by the school district had some impact on the early adopters. As mentioned, the early adopters had been exposed to initiatives on technical and pedagogical support for a longer period than the late adopters. Our study indicates that the support and systematic approach from the local school district may have some impact on how teachers overcome their first- and second-order barriers towards the uptake and use of digital resources and a more SCTB. This may indicate that organisational and pedagogical change calls for a longitudinal perspective before we can trace or measure any kind of impact. Moreover, our findings indicate that a systematic and coordinated approach to professional development towards digital competence initiated from the local school district may help schools and teachers overcome their external and internal barriers towards teaching with digital resources. Nonetheless, maintaining a learning network of teachers and schools requires an open dialogue and an ongoing dialogue and sharing of ideas (Vogt et al., 2015).

The practical implications of this study thus highlight the importance of a systematic and holistic implementation of digital devices, including competence development and facilitating sharing of ideas. Moreover, as demonstrated, systematic professional development initiatives can help schools to overcome barriers to the uptake and use of digital technologies.

One-on-one coverage of digital devices is increasing in many countries, and the trend has been bolstered by the covid-pandemic. The causal relations between technology, organisational support, teaching practice, and student outcomes are complex, and the prevalence of digital devices limits the possibilities for studies using a randomized, controlled experimental design. The present study shows the usefulness of a natural field-experimental design to better understand the long-term consequences of both one-on-one coverage and organisational support on the collaborative communities among teachers and the individual teaching practice.

5.1. Conclusion, limitations, and future research

We believe our findings, as elaborated in this article, address some important issues regarding how teachers and schools may overcome both internal and external barriers related to responsible and targeted pedagogical use of one-to-one coverage for digital devices in schools. Nonetheless, a response rate of above 60% in each of the two groups limits the generalisability of the statistical analyses, as the remaining 35–40% of non-responders might be very different in their work schedule, job interest, and self-efficacy. We cannot disregard the possibility that teachers with less positive perceptions of the one-to-one coverage initiative chose not to participate in the study. Nevertheless, achieving a response rate as high as this is not very common in educational research, at least in Norway. A merger of municipalities during the research period allowed for a natural field experimental design to explore early and late adopter differences. However, with cross-sectional post-test-only data, no causal conclusions can be drawn. Investigating these research questions with an experimental design would, in any case, be practically, politically, and ethically demanding, if not impossible. Yet, our study raises ideas for follow-up studies regarding how local governance bodies may impact pedagogical change and support and overcome teachers' internal barriers towards teaching with digital technology as they approach more student-active teaching and learning methods. While there are numerous studies that address teachers' own perceptions of these types of changes, fewer studies include a more holistic approach involving schools and school districts and their impact and efforts towards pedagogical change. We also recommend more studies that take a longitudinal perspective on these matters, since, at least as demonstrated here, changes take time, and it is important to measure various elements in a longitudinal manner.

CRediT author statement

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Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.compedu.2023.104927.

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