

Knowledge Sharing as a Catalyst: Quantifying Teacher Readiness for Emergency Remote Teaching Toward Sustainable Development

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Abstract

The COVID-19 pandemic triggered an abrupt transition to emergency remote teaching (ERT), exposing systemic vulnerabilities and accelerating practice-based professional development. This study examines how teachers' adaptation to ERT provides insights for designing sustainable professional learning systems. Using learning curve (LC) models, we analyze the dynamics of skill acquisition across subject areas and identify knowledge sharing as a critical factor in competence development. Findings suggest that collaborative learning and digital competence – both of which intensified during the pandemic – should be embedded in teacher education for sustainable development (ESD), ensuring preparedness for future disruptions and fostering lifelong learning.

Keywords: COVID-19, emergency remote teaching, knowledge sharing, learning curve, sustainable development, technology readiness.

Introduction

When the COVID-19 pandemic began, education systems worldwide introduced a new form of teaching – emergency remote teaching (ERT). It could not be compared to conventional online learning or classroom instruction, as most teachers had no experience in the digital environment (Hodges et al., 2020). Since then, much has been written about ERT from teaching (Lemov, 2020; Mirke & Tzivian, 2021; Stevens, 2020; Trust & Whalen, 2020) and learning perspectives (Goudeau et al., 2021; Lepp & Luik, 2021; Serravallo, 2020).

This rapid shift exposed systemic weaknesses (access, well-being) and catalyzed practice-based professional development, and teachers' internal readiness for ERT played a key role in the emergency remote learning process (Usca et al., 2021). Readiness for ERT, motivation, and acceptance of ERT was mentioned as crucial for effective teaching (Hosny et al., 2021; Justis et al., 2020; Scherer et al., 2021; Stevens, 2020). We see this experience as a window for growth both structurally and through the lens of teachers' professional education for sustainable development (ESD). Sustainable learning within ESD requires inclusion, resilience, and openness to lifelong learning (Koc & Liu, 2016; Liu et al., 2022; Monahan et al., 2008; Sterling, 2010; United Nations Educational, Scientific and Cultural Organization [UNESCO], 2017).

Digital competence is part of teachers' professional competence (Skantz-Åberg et al., 2022), and there is research revealing that teachers' digital competence has an impact on students' performance and learning results (Núñez-Canal et al., 2022; Stocchetti, 2014). Among the factors of successful ERT, teachers' digital competence must be underscored, as information and communication technology (ICT) tools and platforms were extensively used to communicate with students and guide their learning.

Collaboration emerged due to unexpected situations with remote teaching and the need for communication among educators. Research shows that group performance is often better than individual, and it can be explained by the synergetic effect among the group members (Thompson, 2020). Hattie explains it with the group members sharing the cognitive burden of the task (Hattie & Yates, 2014). During the crisis, teachers were encouraged to cooperate and share their knowledge about ERT-adapted work methods and ICT tools suitable for ERT in order to leave more time for professional growth (Jansone-Ratinika et al., 2021). Research has revealed the importance of cooperation within teachers' professional learning communities for ensuring emotional well-being as well as the acquisition of professional knowledge (Justis et al., 2020; Olofsson et al., 2021; Ulla & Perales, 2021).

To visually represent and quantify the learning result, a learning curve (LC) can be developed. LC models can show the performance of an organization, group, or an individual within a particular group, reflecting individual progress in time units against the invested resources (costs, work, and effort) (Dar-EL, 2000; Jaber, 2016; Malyusz & Pem, 2014). In this study, we applied and tested LC models in ERT competence development

context. By modelling development of teachers' ERT competence development using LCs, we provide insights for designing sustainable learning processes, for monitoring and steering sustainable teacher education, beyond crisis response.

Readiness for Emergency Remote Teaching

Due to the unexpected character of the COVID-19 crisis, we decided to compare remote teaching to online teaching due to similarities in technology use for the purpose of teaching and learning. Prior literature identifies four readiness elements for online learning – organization (institutional) readiness, faculty (teachers, technical, and administrative staff), course (content, learning materials, assessments), and learners' readiness (Palloff & Pratt, 2002; Simonson et al., 2019). Together, these dimensions offer a comprehensive model for assessing readiness for ERT.

From an ESD perspective, readiness for ERT extends the technical preparedness. It also encompasses the capacity of educational systems and educators to ensure continuity of inclusive, meaningful, and transformative learning under crisis conditions, in alignment with sustainability-oriented values (Sterling, 2010; UNESCO, 2017, 2020).

Accordingly, factors influencing the readiness for ERT can be interpreted as ESD-related competences for learning and teaching (Chi, 2015; Martin, Budhrani, et al., 2019; Serravallo, 2020):

- **Technical skills and digital competence** – These are not only technical skills but the ability to critically and ethically use digital technologies for sustainable learning environments (UNESCO et al., 2018);
- **Previous experience in online or remote learning/teaching** – It contributes to resilience and adaptive capability;
- **Attitudes towards ERT** (awareness of importance) – They include awareness of one's role in ensuring educational continuity and social responsibility;
- **Time management skills, self-regulation** – These skills are essential for sustainable learning processes in uncertain and changing environments;
- **The ability to engage students and to foster their social interaction** during ERT reflects ESD principles of participatory, socially inclusive and learner-centered education;
- **Need and willingness to seek assistance** from colleagues and management – These qualities emphasize collaboration and collective responsibility, which are also core elements in ESD.

Sharing knowledge is crucial for any organization as it means that its employees can exchange their experience, knowledge, and skills (Nazim & Mukherjee, 2016). Importance of knowledge sharing is even greater during circumstances like COVID-19 pandemic, as people are more vulnerable in stressful circumstances. Nazim and Mukherjee mention three elements of knowledge sharing: employee motivation, ICT tools, and knowledge-sharing culture (Nazim & Mukherjee, 2016). Motivation was high during the crisis, ICT tools developed rapidly and knowledge-sharing culture became a must for survival.

Learning Curve Models in Education

Learning curve (LC) is a graphical “curve plotting performance against practice; the course of progress made in learning something” (Merriam-Webster, n.d.). Initially, LCs were used in manufacturing, where employees performed repeated activities and had to acquire new skills after the introduction of new technology or equipment. Later, LC models became widely used also in sociology, biology, economics, urban planning, information technologies, health, and other areas (Tingyan, 1990).

T.P. Wright (1936) was the first to develop an LC for workers of the airplane manufacturing industry with an intention of reducing production costs. Referred to as Wright’s “Log-linear” model (1), it is the first known LC model (Anzanello & Fogliatto, 2011):

$$y = Ax^{-b}, \quad (1)$$

where (A) denotes the theoretical time or cost required to produce the first unit and (y) represents the average time or cost per unit for producing (x) units. The variable (b) signifies the learning rate, depicted by the slope of the curve, and it must lie between 0 and -1. The closer (b) is to -1, the steeper the curve, indicating faster learning and improvement in performance (Jaber, 2016).

Towill’s “constant time model” (1990) suggests developing the LC after an individual has had some time to practice and has adapted to the new task (Anzanello & Fogliatto, 2011), and therefore we consider it the most appropriate for the crisis (2):

$$p = p_c + p_f \left(1 - e^{-\frac{x}{\tau}}\right), \quad (2)$$

where (p_c) represents the employee’s initial performance (measured in units produced per unit of time), and (p_f) denotes the maximum possible performance once the learning process is complete. The variable (x) stands for cumulative operating time, while (τ) is the time constant of the curve. This equation helps determine the time required to reach a specific performance level (Jaber, 2016; Peña et al., 2022). The constant time model is relatively simple, involving only three parameters (Gosling et al., 2019), and is recommended for use when an employee is allowed an adaptation period before data collection begins (Anzanello & Fogliatto, 2011).

Education for Sustainable Development and Professional Development

In teacher education research, sustainability is commonly framed as a multidimensional phenomenon that integrates environmental, social, and economic dimensions (Koskela & Kärkkäinen, 2021). The ESD agenda is strongly aligned with the United Nations 2030 Agenda and the Sustainable Development Goals (SDGs), particularly SDG 4 on quality education and lifelong learning (Agenda 2030 - Österreichische UNESCO-Kommission, n.d.). In the context of teacher learning, this global framing underscores that “quality education” is not only an output measure but also a sustainability concern,

linked to the long-term viability of educational systems and their ability to respond to disruptions and inequalities (Huang et al., 2024).

From the standpoint of teacher learning, ESD further implies that professional development should be continuous, collaborative, and oriented toward transformation of practice rather than one-off training events. Sustainable professional development is frequently described as holistic and transformational, supporting “self-directed learning, participation and collaboration” (Brandisauskiene et al., 2020). This emphasis becomes particularly important during crises, when teachers’ competence development must occur under time pressure and emotional strain, often through peer support, experimentation, and rapid iteration. Briede et al. (2024) capture this expectation succinctly: “teaching demands continuous learning – learning alongside them, learning from them, and constantly evolving” (Briede et al., 2024). Remote teaching without socializing is emotionally difficult, it requires more concentration, and not all people can endure it for a long time.

These ESD expectations connect directly to the notion of learning curves in sustainable professional development. In the present study, “learning curves” refer to the non-linear development of competence over time, shaped by iterative practice, feedback, support structures, and changing contextual demands. Rather than assuming a smooth progression, an ESD lens anticipates that competence development may accelerate, plateau, or regress depending on workload, collaboration opportunities, leadership, and resource availability. This is visible in professional learning designs that emphasize cycles of goal setting, enactment, monitoring, and adjustment. Manal et al. (2024) highlight coaching as one such mechanism: “The value of coaching teachers ... is recognized to provide them with sustainable professional development (SPD)” (Manal et al., 2024, p. 63). They further show that the quality of sustainable professional development is tied to contextual factors – particularly leadership and a collaborative culture – indicating that learning curves are not only individual trajectories but also socially produced patterns embedded in school environments (Manal et al., 2024).

Importantly, ESD-oriented learning curves are accelerated when teachers are supported to translate learning into practice through sustained, practice-connected work. Huang et al. (2024) describe teacher change in blended professional learning as “the behavioral improvement process of teachers learning, practicing, and improving” (Huang et al., 2024, p. 98). This framing aligns with an ESD understanding of competence as enacted capability: teachers consolidate learning when they repeatedly apply pedagogical and technological knowledge in authentic contexts, receive feedback, and refine practice. During COVID-19, this often occurred through collaboration – within teams, professional learning communities, mentoring/coaching relationships, and informal peer exchanges, particularly when teachers needed to redesign instruction, maintain student engagement, and ensure equitable participation at a distance.

The Research Aim and Methodology

The study aims to evaluate how teachers’ readiness for ERT evolved during COVID-19 pandemic and to model this development using LC models. The research objectives (RO)

are listed below:

RO1. To analyze changes in teachers' professional competence and lifelong learning processes during the pandemic.

RO2. To test whether mathematical LC models can represent and interpret changes in ERT skills.

RO3. To explore how LC models, adapted for crisis conditions and aligned with ESD principles, can help develop sustainable professional development for teachers.

Research Design

Based on our previous research on adults' (Mirķe et al., 2019) and teachers' readiness for online learning (Mirķe & Tzivian, 2021), a self-evaluation survey to measure teachers' "Readiness for Emergency Remote Teaching" was developed. It consisted of forty-seven five-point Likert-scale items and demographic questions. The questionnaire was based on validated tools for assessing teachers' readiness for distance learning (Chi, 2015; Hung, 2015; Martin, Wang, et al., 2019) across five blocks:

- Assistance (individual/institutional support);
- Engagement (communication and student social interaction);
- Work organization (forms and methods chosen for ERT);
- Attitudes (toward remote teaching);
- Digital resources (application and use).

These blocks correspond to global sustainable development goals and especially the goal of quality education as well as 2030 Education Agenda: equity, inclusion, adaptive practices, where lifelong learning and digital competence, and accessibility of education play an important part (Agenda 2030 - Österreichische UNESCO-Kommission, n.d.).

Participants and Sampling

The study sample consisted of Latvian general education schoolteachers (N = 2111) from all educational levels (except higher education). Participation criteria included experience with ERT during the pandemic. Respondents were invited via electronic mail and a publication on an educator's web-portal. The study took place in May 2020 and May 2021 (two data collection points).

Development of Learning Curve Models

Readiness for ERT was computed for each subject area (SA) and analyzed across two data points – May 2020 and May 2021. LC models were developed based on Towill's "constant time model" (Anzanello & Fogliatto, 2011) which accounts for adaptation periods before data collection.

A system of equations was developed to compare the two data points and evaluate readiness for ERT change over time (3).

$$\begin{cases} p_1 = p_f \left(1 - e^{-\frac{t_1}{\tau}} \right) \\ p_2 = p_f \left(1 - e^{-\frac{t_2}{\tau}} \right) \\ t_2 - t_1 = t_x \end{cases} \quad (3)$$

In Equation (3), (p_1) represents the teacher's readiness at the start of the readiness for ERT study (it is the first measurement in 2020), and (p_2) represents readiness at the end of the ERT study (it is the second measurement in 2021). The maximum possible level of readiness for ERT, (p_f), was known to be 32. The variable (t_1) indicates the time when the first measurement is taken (May 2020) and when the respondent has reached the readiness level (p_1), while the variable (t_2) indicates the time of the second measurement (May 2021), when the teacher has reached the next readiness level (p_2). The time difference between the first and second measurements is denoted by (t_x), which is known to be 12 months (from May 2020 to May 2021). The variable (τ) represents a time constant, reflecting the period required for each teacher to independently acquire the necessary knowledge or experience.

Three possible scenarios were developed for the study:

1. Readiness for ERT developed without prior experience;
2. Readiness for ERT was influenced by accumulated ICT experience;
3. Readiness for ERT was affected by knowledge sharing within teacher groups.

For the third scenario, a new variable (c), representing knowledge dissemination ($0 < c < 1$), was introduced to capture the effect of peer collaboration and collaborative learning on learning trajectories. This adaptation aligns with ESD principles, emphasizing collective responsibility and participatory learning.

Research Results and Discussion

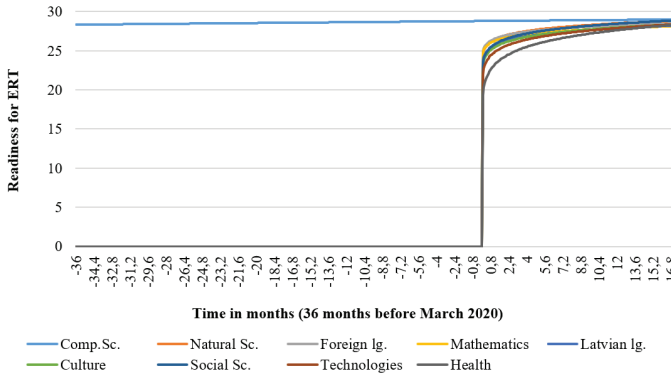
Learning Curve Models and Competence Development

Based on our measurements and theoretical knowledge, three theoretically possible LC models were tested to model teachers' readiness for ERT:

1. Readiness for ERT was developed **without prior experience**. This model was rejected because calculations produced negative values, indicating that all teachers had basic digital skills before the pandemic.
2. Readiness for ERT was **influenced by accumulated ICT experience** (Figure 1). This model explained competence growth for Computer Science teachers but failed to explain other subject areas, suggesting that prior ICT experience was not sufficient. There must have been other factors influencing the readiness for ERT.
3. Readiness for ERT was **affected by knowledge sharing within groups**. Introducing a knowledge-sharing factor, (c), produced an LC model that aligned with observed trajectories across subject areas (Figure 2).

Figure 1

Development Dynamics of Readiness for ERT in All Subject Areas 36 Months Before and 16 Months After the Start of the COVID-19 Lockdown



Knowledge Sharing as a Critical Variable

Mathematical calculations and curves of the first two LC models did not explain what had influenced the slope of LC for most teacher groups, except Computer Science teachers. It was not considered in the first two scenarios and LC models. The variable (c) was introduced to represent the possible knowledge-sharing factor (where $(0 < c < 1)$) within a group. We assumed that while ERT process occurred, one individual acquired a new skill or knowledge useful for ERT process, they shared the new knowledge with others in the same SA (or beyond). The new LC model is described in Equation (4):

$$\frac{p}{p_f} = \left(1 - e^{-\frac{t}{\tau}}\right)^c, \quad (4)$$

where variable (c) is the variable of knowledge sharing ($0 < c < 1$). Other variables were as in the previous system of equations (3).

A completely new system of equations was created including the new variable (5).

$$\begin{cases} \frac{p_1}{p_f} = \left(1 - e^{-\frac{t_1}{\tau}}\right)^c \\ \frac{p_2}{p_f} = \left(1 - e^{-\frac{t_2}{\tau}}\right)^c \\ t_2 - t_1 = t_x \end{cases} \quad (5)$$

Using mathematical methods, variable (c) can be expressed in Equation (6).

$$\frac{\ln 0,814}{\ln\left(1 - e^{-\frac{3}{\tau}}\right)} = c = \frac{\ln 0,881}{\ln\left(1 - e^{-\frac{15}{\tau}}\right)}. \quad (6)$$

We selected the Design and Technology teachers' group results for the LC model calculations. Variables for the Design and Technology group were as follows (p_1 and p_2 are group responses from the quantitative study):

$$p_f = 32$$

$$p_1 = 26.05$$

$$p_2 = 28.19$$

$$t_x = 12$$

For the Design and Technology group, the knowledge-sharing factor (c) was 0.05 (the numerical method can be observed in detail in Annex 1).

Data and estimated knowledge-sharing factors for all subject areas are shown in Table 1.

Table 1

Performance and Estimated Knowledge-Sharing Factor in All Subject Areas

Subject area	p_1 , performance after 3 months	p_2 , performance after 15 months	p_x , change in performance	c , knowledge- sharing factor
Health and Sports	24.95	28.05	+3.1	0.076
Design and Technology	26.05	28.19	+2.14	0.050
Social Science	26.88	28.71	+1.83	0.042
Culture and Arts	26.45	28.21	+1.76	0.040
Latvian Language	26.56	28.08	+1.52	0.035
Natural Science	27.28	28.71	+1.43	0.032
Foreign Language	27.21	28.39	+1.18	0.026
Mathematics	26.9	28.03	+1.13	0.026
Computer Science	28.83	28.97	*	*

*Computer Science results are different due to high initial digital competence; knowledge distribution within the group for this group is insignificant.

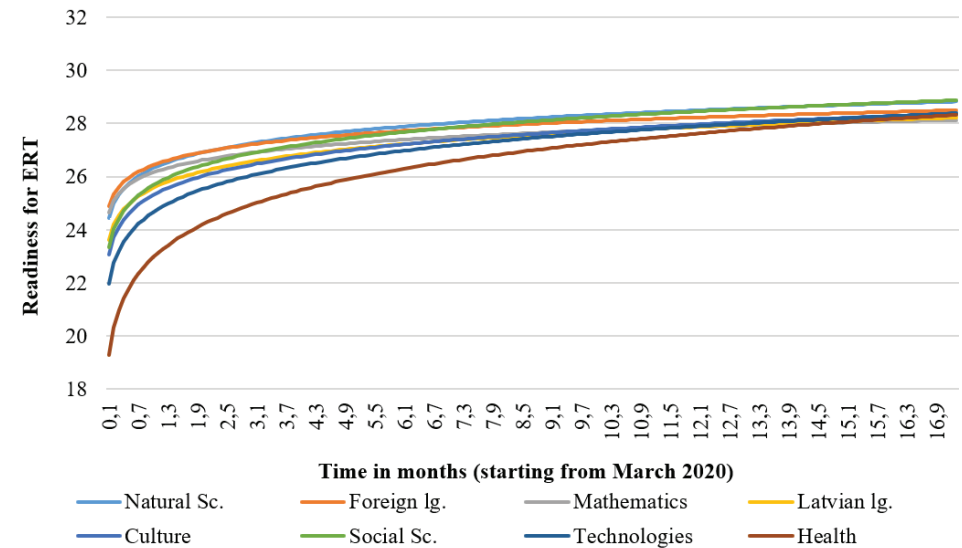
Results reveal significant variation, showing that each subject area has different in-group knowledge-sharing factor (Table 1):

- Highest knowledge sharing occurred in Health and Sports group (0.076) and Design and Technology (0.05), reflecting active collaboration and knowledge sharing within the group;
- Lowest values were observed in Foreign Languages and Mathematics (0.026), indicating more isolated professional environments;
- Computer Science teachers' within-group sharing was insignificant due to high initial ICT competence.

These findings confirm that collaboration accelerated during the pandemic. Teachers who actively engaged in professional learning communities within the school or other

environment and exchanged ERT strategies, ICT solutions, progressed faster, reducing stress and improving work quality – consistent with research on professional learning communities (Lantz-Andersson et al., 2018; Ulla & Perales, 2021).

Figure 2
Readiness for ERT Development Dynamics During the First 17 Months After the COVID-19 Lockdown (Computer Science Group excluded)



The analysis of three learning curve models reveals that competence development during ERT was not uniform across all subject areas. The first model – assuming readiness developed without prior ICT experience – was rejected because all teachers had acquired some basic ICT knowledge and skills before the pandemic. The second LC model – considering accumulated ICT experience – explained Computer Science teachers’ results, but failed for other subject areas. The third model introduced the knowledge-sharing factor (c) to capture the effect of peer collaboration and within-group sharing, producing results consistent with observed patterns.

Before the pandemic, educators predominantly possessed theoretical knowledge regarding classroom technology, with limited practical application of newly acquired skills. The pandemic conditions necessitated the adoption of novel communication platforms, digital assessment tools, and other technological resources to ensure the continuity and quality of education. Consequently, teachers across various disciplines developed the capabilities to facilitate ERT at differing rates. Computer Science educators developed their technological competencies through individual study since the introduction of the subject “Computational Mathematics and Programming” in Latvian schools and the advent of the Internet, and the implementation of ERT work represented a novel application of ICT for these educators. Teachers from other subject areas had to acquire the skill of organizing remote learning as a new competency. Our study confirms that knowledge sharing within a group was a decisive factor in accelerating professional competence.

Co-existence for Education for Sustainable Development

From an ESD perspective, the pandemic highlighted the need for professional development systems that are:

- collaborative – fostering peer collaboration and knowledge sharing to build resilience;
- inclusive – addressing digital divides and ensuring access to resources;
- continuous – supporting growth through practice, reflection, and continuous improvement.

Embedding these principles into teacher professional development system and teacher education ensures preparedness for higher quality co-existence, future disruptions, and aligns with UNESCO's vision for teachers' learning through collaboration and innovation (UNESCO, 2025). LC modelling offers a practical tool for monitoring progress and designing interventions that strengthen collective capacity rather than focusing on individual performance.

From an ESD perspective, technology integration should be approached critically and pedagogically. In networked societies, digital tools can support new forms of participation and citizenship education and can enrich ESD pedagogy when paired with critical understandings of technology's social role. Huckle (2012) asks how teacher education should respond to new ICT and considers the potential of Web 2.0 technologies to enrich ESD in classrooms (Huckle, 2012).

In the COVID-19 period, this question became urgent: teachers were compelled to use digital systems at scale, and the sustainability challenge shifted toward ensuring that technology-enabled learning remained inclusive, pedagogically meaningful, and connected to the broader aims of ESD.

Conclusions and Recommendations

ESD-Oriented Learning

The COVID-19 crisis foregrounded the practical convergence of ESD principles and everyday pedagogy, particularly when schooling shifted to remote learning. Crucially, this disruption challenged not only technical routines but also the relational and dialogical foundations of teaching – elements that are foundational to ESD, with emphasis on learners' capacity to navigate complexity, uncertainty, and responsibility. In this sense, ERT became an “authentic testbed” in which ESD principles were enacted under the conditions of constraint.

Our results further reinforce the whole-school approach to ESD (Wals & Benavot, 2017), demonstrating that when teachers actively participate in localized communities of practice – exchanging strategies, reflecting collectively, and co-developing ERT solutions – the outcomes extend beyond instructional effectiveness. Such environments are associated with enhanced teacher well-being, reduced stress levels, and improved overall school performance.

Learning Curve Modelling

Learning curve models offer significant potential for analyzing professional development, particularly where they are integrated with machine learning-supported data. This enables information on resource allocation and management system design. However, certain limitations must be considered: (1) **LCs are context-dependent across industries**, (2) **LCs are sensitive to available data collected at specific times**, and it is crucial to gather this data as accurately as possible and to repeat the data collection at regular intervals. Moreover, (3) **LC patterns are localized**, reflecting the characteristics of individuals in the specific group of individuals whose data is included in the model (Peña et al., 2022). These limitations underscore the need for cautious generalization and regular data collection when applying LC models to educational contexts.

Collaboration and Knowledge Sharing

Building on prior research, we suggest ESD-oriented teacher professional learning a threefold design: (a) **equity-driven** (addressing participation and the digital divide), (b) **collaboratively enabled and practice-embedded** (linking learning to professional agency and everyday teaching), and (c) **iteratively structured** (supporting learning curves through cycles of enactment, monitoring, and refinement). These principles provide a foundation for interpreting how pandemic-era collaboration shaped teachers' learning trajectories and how this affects building sustainable teaching competence beyond crisis conditions.

Teacher **collaboration and knowledge sharing** – across formal and informal, large and small professional learning communities – **emerged as the dominant activity of professional development** during the pandemic. This collective learning approach was instrumental for achieving functional readiness for remote teaching across all subject domains. It was an important and structural driver linking crisis-affected adaptation, learning curve acceleration, and long-term advancement of ESD-oriented teaching competence. In this sense, collaboration functioned not only as a pedagogical strategy but as a systemic condition for sustainability, simultaneously supporting professional competence, organizational resilience, and the broader goals of ESD – the evidence positions teacher collaboration as the critical infrastructure of resilient and sustainable education systems, linking individual learning curves with institutional capacity and long-term ESD outcomes.

These findings align with UNESCO's (2025) recommendations with emphasis on collaborative professional community engagement as a cornerstone of educational resilience. From a policy perspective, this suggests a shift from ad hoc collaboration to institutionalized professional learning communities to encourage knowledge-sharing culture in educational organizations.

Key Takeaways

1. **Digital competence is a resilience capacity.** The pandemic accelerated teachers' digital competence development but revealed systemic gaps in readiness for

emergency remote teaching and institutional support. Readiness for ERT is not optional but essential for education system stability.

2. **Learning curves enable strategic and data-driven development:** LC models provide a framework for understanding and informing data-driven professional development strategies beyond crisis response toward sustainable system improvement.
3. **Collaboration accelerates competence development.** Our findings identify professional knowledge-sharing communities as a critical accelerator of learning, highlighting peer interaction and within-group knowledge sharing as primary drivers of both the speed and depth of teachers' professional learning.

Implications for Practice and Further Research

Our findings position teacher collaboration as a structural driver of competence development, rather than a supportive condition. Schools should therefore institutionalize professional learning communities and embed knowledge sharing into daily practice. Digital competence needs to be reframed as a resilience capacity, supported through collaborative, equity-oriented, and iterative professional learning. Learning curve (LC) models – especially those incorporating the knowledge-sharing factor (c) – can serve as tools for monitoring and guiding professional development.

Future research should refine LC models by integrating social variables, particularly knowledge sharing, and test them across contexts. More longitudinal and multi-point data are needed to capture non-linear learning trajectories. Additionally, studies should examine how collaboration, leadership, and organizational conditions jointly shape learning curves, and extend analysis to diverse educational systems to improve generalizability in non-crisis conditions.

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Annex 1

Use of Numerical Methods to Verify Variable Values
Data of the Design and Technology Subject Area Group

p_f	32	p/p_f	$=\text{LN}(1-p/p_f)$
p_1	26.05	0.814063	-1.68234 LN1
p_2	28.19	0.880938	-2.12811 LN2
τ	26.92019		-0.44576

months		years
τ	26.9	2.2
t1	45.3	3.8
t2	57.3	4.8

$\log(p_1/p_f)$	$\log(p_2/p_f)$	Tau, τ	$\log(1-\exp(-3/\tau))$	$\log(1-\exp(-15/\tau))$	$\log(p/p_f)/\log(1-\exp(-3/\tau))$	$\log(p_2/p_f)/\log(1-\exp(-15/\tau))$	difference
-0.206	-0.127	5	-0.796	-0.051	0.258	2,482	2.22381
-0.206	-0.127	6	-0.933	-0.086	0.221	1,48	1.259519
-0.206	-0.127	7	-1.054	-0.125	0.195	1,016	0.820653
-0.206	-0.127	8	-1.162	-0.166	0.177	0,761	0.584528
-0.206	-0.127	9	-1.261	-0.209	0.163	0,606	0.442397
-0.206	-0.127	10	-1.35	-0.252	0.152	0,502	0.34973
-0.206	-0.127	11	-1.433	-0.295	0.144	0,429	0.285612
-0.206	-0.127	12	-1.509	-0.338	0.136	0,376	0.239167
-0.206	-0.127	13	-1.58	-0.379	0.13	0,335	0.204282
-0.206	-0.127	14	-1.646	-0.419	0.125	0,302	0.1773
..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..
-0.206	-0.127	178	-4.092	-2.516	0.05	0,05	0.000115
-0.206	-0.127	179	-4.097	-2.521	0.05	0,05	0.000076
-0.206	-0.127	180	-4.103	-2.526	0.05	0,05	0.000037
-0.206	-0.127	181	-4.108	-2.532	0.05	0,05	-0.000001
-0.206	-0.127	182	-4.114	-2.537	0.05	0,05	-0.000039
-0.206	-0.127	183	-4.119	-2.542	0.05	0,05	-0.000076
-0.206	-0.127	184	-4.124	-2.547	0.05	0,05	-0.000113
-0.206	-0.127	185	-4.13	-2.553	0.05	0,05	-0.00015